NBS BUILDING SCIENCE SERIES 120

Guidelines for Stair Safety

ARTMENT OF COMMERCE • NATIONAL BUREAU OF STANDARDS

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Guidelines for Stair Safety

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Cover: *This simulation depicts a fall down a stair which could have been prevented through careful attention to stair design.*

LIST OF TABLES

PREFACE

During the course of this project, a number of individuals contributed to the technical research on stair safety, to the formulation of design guidelines, and to the preparation of this report. Mr. John Archea*, formerly with the Architectural Research Program of the Center for Building Technology, National Bureau of Standards (NBS), served as project leader, principal investigator, and principal author of the design guidelines. In collaboration with Dr. C. Anderson Johnson (also formerly with NBS), Mr. Archea designed and conducted basic research studies which led to the formulation of a conceptual model of stair use. This model, in turn, led to the delineation of the design guidelines.

Within the National Bureau of Standards, the basic research effort was assisted by Drs. Robert Wehrli and Stephen Margulis, Ms. Candace Roat, and Mssrs. Kenneth DeCorte, Larry Steel, and Amon Young. Dr. Wehrli, former chief of the Architectural Research Program, NBS, and Dr. Margulis provided valuable editorial review and guidance. Ms. Roat, formerly with NBS, gathered technical and bibliographic materials, and conducted data analyses. Mssrs. Steel and Young, both formerly of NBS, developed data scoring techniques and assisted with data gathering and scoring procedures. Mr. DeCorte provided a detailed review of the model building codes. Mr. William Beine of NBS provided an insightful and thought-provoking critique of the entire document. Finally, the authors wish to thank Miss Tracey Kistler for her untiring efforts and patience during the typing of numerous drafts of this manuscript.

Several experts from outside the National Bureau of Standards were called upon to provide technical assistance and guidance. Videotapes of stair use behavior were provided under contract by Mr. Asher Derman of the University of Texas, Dr. Leon Pastalan of the University of Michigan, Ms. Virginia Ayers of the Environmental Analysis Group, Seattle, Washington, and the members of the Duke University Media Center. A critical incident analysis of several videotapes was conducted by Dr. John Templer of Atlanta, Georgia. The firm of Carson Consultants provided a survey and inventory of residential stairs in the Milwaukee, Wisconsin area. In addition, Dr. Ifan Payne of Kansas State University prepared an annotated bibliography of the literature on stair accidents and pedestrian research, and a glossary of terms. Finally, Drs. Alton DeLong and Robert Brungraber provided technical assistance on important aspects of stair use behavior and stair surface characteristics.

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ABSTRACT

This report summarizes information and research in the area of stair use and provides design guidelines for improving stair safety. These guidelines are directed toward seven major categories of stairway design and construction: (1) structural integrity and quality of stairs, (2) physical attributes of stair surfaces, (3) appearance of stair surfaces, (4) handrails, (5) physical attributes of the surrounding stairway environment, (6) appearance of the surrounding stairway environment, and (7) signs and symbols.

In general, the recommendations offered in this report derive from the premise that stairway accidents are caused by human perceptual errors, which are frequently triggered by some flaw in the design or construction of stairways themselves. Evidence describing the severity and frequency of residential stairway hazards, and supporting premises underlying design guidelines were obtained from epidemiological, experimental, exploratory, and survey research sources. General directions for future investigation are suggested.

Key words: Accidents; architectural design; architectural psychology; architectural research; building codes; building design; building regulatory standards; floor coverings; home safety; safety standards; stair safety; stairway design.

SI CONVERSION UNITS

The units and conversion factors given in this table are in agreement with the International System of Units or SI system (Systeme International d'Unites). Because the United States is a signatory to the 11th General Conference on Weights and Measures which defined and gave official status to the SI system, the following conversion factors are given.

Length

1 in = 0.0254* meter

1 ft = 0.3048* meter

Area

1 in^2 = 6.4516* x 10^{-4} $meter^2$

1 ft^2 = 0.0929 meter

Illumination

1 ft candle = 10.76 lux

Facing page: *The appearance and texture of stair surfaces frequently make it difficult to see the tread edges.*

---

* Exactly

1. INTRODUCTION

1.1 BACKGROUND AND OVERVIEW OF RESEARCH

For each year since 1974 the Consumer Product Safety Commission (CPSC) has determined that stairs, ramps and landings are among the two most hazardous consumer products in the United States. In 1974, for example, stairs were the most hazardous consumer product for adult women. In 1976, some 540,345 stair accidents resulted in injuires serious enough to require emergency hospital treatment. In addition, approximately 4,000 persons died from their injuries. These estimates represent only

those injuries serious enough to require hospital attention. In fact, total stairway accidents are estimated to run as high as two million per year (Asher, 1978). Table 1 provides an estimate of various types of accidents upon stairs in 1975. These accidents vary in severity from simple missteps to deaths.

The frequency and severity of stairway accidents led the U.S. Consumer Product Safety Commission (CPSC) to sponsor research at the National Bureau of Standards (NBS) into ways to reduce the frequency and severity of residential stairway accidents. Research at NBS was intended to support the development of guidelines and recommendations for increasing stair safety.

This report is intended to accomplish three objectives. The first, treated in Section 1, is the provision of an historical overview of the investigation of stair safety performed by NBS. The second is the provision of design guidelines and recommendations for increasing stair safety. Thus, Section 2 addresses recommendations related to safety in residential stairs, where the term "residential" refers to single-family dwellings, multi-family dwellings, high-rise apartments and condominiums, and similar residential structures. Finally, Section 3 provides general conclusions and recommendations for further research to improve knowledge about stair use behavior and, hence, stair safety.

1.1.1 Background to the Problem of Stair Safety

As an introduction to the problem of stair safety, Templer (1974, p. 21) commented that stairs force a pedestrian to cross a regular or irregular set of barriers to which, "judging from the evidence of physiological metabolic studies (Fitch, et al., 1974), we are ill-suited. We are well suited to walking great distances on the level or over gently undulating ground. But stairs demand from us an unusual energy gait, coupled with (or producing) a very high rate of energy expenditure". Both of these demands lead to a higher likelihood of falls or missteps. Templer commented further that stairs are bad places to have falls, particularly in descent, for the fall may be extended down the stairs. In addition, the probability of serious injury can be increased by the sharp edges of the stair tread nosings. Yet, the danger of injury during stair use is often overlooked because stairs are such a familiar element of a building.

As NBS assessed the problems of ensuring user safety on stairs, it became clear that achieving such safety required an understanding of normal stair use behavior, as well as a knowledge of sound stair design principles. This concern led to a focus upon the user's perceptual and motor processes during stair use. These processes were viewed as linked to accident-producing errors which could be triggered by inadequate or misleading physical characteristics of the stairs and their surroundings. As a result, the NBS research centered upon the perceptions and behavior

TABLE 1 - ESTIMATED RATES OF INCIDENTS ON STAIR FLIGHTS IN 1975

Incident Type	Incidents/ Year
Flight Uses	1,953,000,000,000
Noticeable Missteps	264,000,000
Minor Accidents	31,000,000
Disabling Accidents	2,660,000
Hospital Treatments	540,000
Related Deaths	3,800

Sources: This table is derived from data compiled from the National Electronic Injury Surveillance System (NEISS) by the Consumer Product Safety Commission; from a Survey of Stair Use and Quality conducted by Carson Consultants, Inc. of Milwaukee, Wisconsin; and from videotapes of stair use analyzed by the National Bureau of Standards.

of the individual as he* negotiated the stairs, rather than upon the victim's self-report of an accident, or upon the traditional measures such as stair capacity or flow rate, or physical design principles.

1.1.2 Overview of Research

In this section, the research approach taken by NBS is reviewed to provide an historical overview of the directions followed. These include review of the literature and building codes, analysis of video-taped stair-use data, inventory of stairs and stair use patterns, and the development of a stair use model.

The effort at NBS was intended to determine the behaviors that characterize successful and unsuccessful stair use, as well as to ascertain specific design features that could be related to both success and accidents.

Research at NBS began with a review of the published literature on stair safety, existing codes and standards, and in-depth reports of stair accidents compiled through CPSC's NEISS system. Initially these sources were reviewed to determine if statistical evidence existed that linked particular design problems to types of stair accidents or to special user groups. The next step was an extensive review of the literature on stair safety research and design, and the preparation of an extensive annotated bibliography. This included a glossary of terms, a listing of presumed causes, and a compilation of design recommendations from the references cited, portions of which are reported in this document. At the same time, a detailed review was made of the 475 accidents in the in-depth follow-up survey of stair accidents reported through the NEISS (National Electronic Injury Surveillance System) program of CPSC.

Although the review of the literature and the in-depth NEISS reports provided an overall understanding of the frequency and kind of accidents on stairs, it did not provide a clear differentiation of behaviors associated with either accidents or successful stair uses. The review also provided little if any data that identified stair design conditions associated with either successful or unsuccessful stair use (accidents). Similarly, a review of codes and standards failed to provide insight into the underlying causes of stair accidents or into the physical prerequisites for successful use of stairs.

Following the reviews of the literature, accident data, and codes, an accident-behavior model was developed which stressed the importance of perceptual-kinesthetic cues. This model served as a framework for testing ideas about stair use behavior, for developing criteria for safer stair design, and for developing and implementing research.

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* The pronoun "he" refers to both the masculine and feminine gender throughout this report.

In addition, NBS undertook an extensive research effort in which user behaviors were recorded with videotape in a wide range of stair situations. These tapes were analyzed to determine "normal" head, eye, and foot movements during a person's approach to, and descent of, a stair. The analysis also included a statistical treatment of accidents and missteps which occurred during the data recording. NBS also conducted a survey of attitudes toward, and conditions on, stairs in residential settings in a major urban area. These data were used to support the perceptual model of stair use which emphasized the importance of the conspicuousness of stair characteristics and hazards.

Each approach to the analysis of stair behavior is reviewed briefly in Section 1. Then, guidelines for improving the safety of residential stairways are presented in Section 2. Finally, a general summary and recommendations for further research on stair use are discussed in Section 3.

1.2 RESEARCH APPROACH AT NBS

1.2.1 NEISS Reports

As noted earlier, the first step involved the examination of stair accident reports in the NEISS index and the general stair literature. Since 1973, CPSC has gathered product-related accident and injury data through the National Electronic Injury Surveillance System (NEISS). The NEISS gathers daily reports on injuries treated in 119 hospital emergency rooms across the United States. These brief reports include data on the sex and age of the victim, date and time of the accident, the nature of the injury, and the type of product involved. Some of these accidents are then selected for an additional in-depth investigation which includes interviews with victims and witnesses as well as detailed examinations of the accident site.

One of the first steps in the NBS research was to examine all of the NEISS in-depth investigations of stair accidents which CPSC had compiled. Unfortunately, the accidents which had been included in the initial in-depth investigations were not selected systematically and, therefore, they could not be analyzed statistically. Thus, no statistically sound relationship could be determined between specific design features and stair accidents.

Even though the NEISS in-depth investigations did not provide a comprehensive basis for developing design guidelines, the data reported for 476 stair accidents were tabulated according to the categories listed in Table 2. Although these tabulations could not be analyzed statistically, they were thoroughly examined at several points during the research at NBS to identify the range of hazards, victims, and injuries associated with stair accidents. Selected accidents from these in-depth reports are described later as illustrations of specific stair hazards in the Guidelines section of this report.

TABLE 2 - KINDS OF DATA CONTAINED IN THE NBS TABULATION OF IN-DEPTH NEISS REPORTS

IDENTIFICATION

Age
Sex
Handedness
Height
Weight
Occupation
Locations of stairs/kind of building
How long lived in own home
Location of stairs within building
Design of stairs
Aloneness
Direction of travel
Direction of fall
Where fall initiated
How far fell
Cause
Environmental hazard
Individual extenuating circumstance
Location of injuries
Diagnosis
Number of activity days lost
Number of days of restricted activity
Date of injury
Time of day
Day of week
Number of hours between injury and diagnosis
Accident description

1.2.2 Literature Review

A parallel effort with the NEISS report analysis involved an investigation of the literature on stair safety. In this effort, seven categories of stairway research and design data were identified. Among the specific types of literature examined were: (1) research on stair accidents themselves; (2) research on accident etiology in general; (3) research on the physiology of human locomotion on stairs and on level surfaces; (4) research on perception and information processing; (5) research on pedestrian behavior in general; (6) research on the psycho-motor limitations of special subpopulations such as the elderly; and (7) research on slip-resistance and other surface characteristics. In addition, references on accident research methods and on existing design guidelines or standards were gathered for continuing reference. Finally, a table was developed which included the causes of stair accidents as reported in the research literature. (See Table 3.)

During the literature review, a number of important sources were identified. Many of these, such as the WHO Chronicle (1966) were epidemiological in nature, identifying broad patterns but not developing a sound statistical correlation between stair accidents and their antecedent causes. Other similar sources included Backett (1965) who documented a number of stair accidents in the home, McGuire (1971) and Sheldon (1960) who discussed design factors related to stair (and other) accidents among the elderly, and Grandjean (1973) who provided design recommendations for improving stair safety in the home. A report prepared by Teledyne-Brown Engineering (1972) for HUD set forth a coverage of stairway hazards and recommendations for the design and treatment of safe stairs. In addition, Fruin (1971) provided extensive basic information on the patterns of behavior and use of stairs, as well as design recommendations based upon pedestrian movement on public stairs.

Several other major sources discussed the nature and causes of stairway accidents. These included Esmay (1961) who interviewed victims of 101 stairway accidents in the home to determine the nature and causes of stairway accidents; Gowings (1961) who surveyed 1674 stairways in 440 dwellings in Warren County, Pa. and enumerated numerous design faults for later correlation with stair accidents, and Velz and Hemphill (1953) who surveyed the frequency of injuries in a sample of 2456 homes to determine background data for planning home safety programs. Finally, a major source proved to be Templer's doctoral dissertation (1974) which reviewed the existing stair research, assessed human gait and energy expenditure on a laboratory stair treadmill, and observed different groups of people on public stairs. These and other sources will be identified in Section 2 for use as evidence in support of specific guidelines for reducing the hazardousness of a particular stair condition.

1.2.3 Codes and Standards

Another NBS effort included the review in 1974 of the recommendations for stair design contained in the five model codes, as well as the FHA Minimum Property Standards. The codes referred to were the Life Safety

TABLE 3 - LITERATURE REVIEW

Reported Cause of Accident	Level of Reporting	Reference
Addition of Nose Pieces Causing a Lip Where They Meet the Tread	Field study	Harper, Warlow and Clarke: 1967b
Arms full	Field study	Miller and Esmay: 1961
	Survey	"Stairs, Ramps and Landing": 1974
Articles left on stairs	Survey	McGuire: 1971
Badly maintained floor	Survey	Agate: 1966
Broken steps	Survey	"Stair, Ramps and Landings" 1974
	Survey	McGuire: 1971
Carpet loose	Survey	McGuire: 1971
Caught heel on step	Field study	Esmay: 1961
Caught toe on nose of step	Field study	Esmay: 1961
Changes of levels	Survey	Joliet and Lehr: 1961
Descending the stairs	Survey	Templer: 1974b
Door swinging over stairway	Survey	McGuire: 1971
Falls	Survey	Iskrant and Sullivan: 1960
	Survey	Templer: 1974
	Field study	Dickson: 1964
	Field study	
Handrail design includes sharp surfaces	Survey	McGuire: 1971
Handrail missing	Survey	McGuire: 1971
	Survey	Templer: 1974
Handrails	Field study	Gowings, D.D.: 1961
Horizontal force of foot directed forward	Field study	Harper: 1962

TABLE 3 - (continued)

Reported Cause of Accident	Level of Reporting	Reference
Poor lighting	Survey	Agate: 1966
	Survey	Neutra and McFarland: 1972
	Survey	Stairs, Ramps and Landings: 1974
	Field study	Sheldon: 1960
	Survey	McGuire: 1971
	Survey	Wheatley: 1966
	Survey	Templer: 1974
Poor railings		"Stairs, Ramps and Landings: 1974
	Survey	Wheatley: 1966
Poor tread surfaces		"Stairs, Ramps and Landings: 1974
Poor workmanship and maintenance	Survey	Templer: 1974
Riser Height		Gowings, D.D.: 1961
Riser number		Gowings, D.D.: 1961
Rubber on wet floors	Field study	Harper: 1962
Running		"Stairs, Ramps and Landings: 1974
Sharp edge on step	Survey	McGuire: 1971
Shaky stairs	Survey	Wheatley: 1966
Slipped	Field study	Miller and Esmay: 1961
		Neutra and McFarland: 1972
	Survey	Templer: 1974
		Esmay: 1961
Slippery tread	Survey	McGuire: 1971
	Survey	Templer: 1974
Slippery floors	Survey	Joliet and Lehr: 1961
Slipping and tripping	Field study	Texas State Dept. of Health: 1961
	Field study	Texas State Dept. of Health: 1961
	Field study	Texas State Dept of Health: 1961
Spilled liquid	Survey	Wheatley: 1966
Stair flight too long	Survey	Templer: 1974
Stairway width		Gowings, D.D.: 1961

Code (LSC), the Uniform Building Code (UBC), the Southern Standard Building Code (SSBC), the National Building Code (NBC), and the Basic Building Code of the Building Officials Conference of America (BOCA), as well as the Federal Minimum Property Standards (MPS) for one and two-family housing, multi-family housing, and care-type housing.

In general the codes specify minimum stair and landing width as well as minimum headroom. They also specify tread depth and riser height, although there is considerable variation in the exact measurements. Minimum and maximum numbers of risers between landings are frequently stipulated. The codes in general require handrails to be used where needed to keep occupants from falling. Yet there is wide variation in recommended handrail height, as well as in the number of handrails. Finally, there is considerable variation among the model codes with respect to the requirements for riser/tread uniformity. Some codes specify the extent of variation in inches while others only state that there should be uniformity throughout the run of the stair. Thus, a review of the codes indicates the nature of the physical characteristics of stairs believed to be important for ensuring stair safety. Details of code requirements are given in Appendix D.

1.2.4 Model of Stair Safety and Use

1.2.4.1 Introduction to Model

Given the fragmented understanding of stair use and stair accidents that emerged from the reviews of the literature, prevailing codes and standards, and the NEISS in-depth accident reports, it became necessary to develop a conceptual framework for organizing the NBS research. This framework, which eventually became known as the stair use and behavior model, was developed at the outset of the stair safety research at NBS. Like all hypotheses, the model grew from a combination of common sense, informal observations, reviews of specialized literatures, logical deductions, and a close re-examination of the literature, standards, and incidents.

Analysis of human behavior recorded in seemingly non-hazardous environments led to the identification of a number of environmental factors that might interfere with a user's visual and kinesthetic assessment of prevailing stair conditions. Successful and unsuccessful stair use was also analyzed in terms of the user's test of his assumptions as he encounters a stair and responds to unanticipated discontinuities in its structure or that of its surrounding environment. Thus the presence of unambiguous visual cues and the absence of distractions can be directly related to the design of safe stairs. As a result, the approach to the development of performance criteria for stair design stressed the specification and corroboration of an information processing and performance model of successful stair use.

1.2.4.2 Detailed Discussion of the Model

The model of stair use will be discussed according to the sequence of events that occurs in normal stair use. The model begins with the user's expectations of his ability to use stairs. These are based upon experience gained through his previous stair use. Thus, the user has an internalized image of stairs in general, and of his own ability to negotiate stairs in particular. Once he has identified a stair as being in his path of movement, the family of stored images concerning stairs and previous stair use is activated.

After the user has realized that he is approaching a stair, a perceptual test is made. The user's internalized image of the stair is checked against his sensory perception of the stair. Once the image and the actual perception of the stair correspond, the user enters the stairway with some assurance that he will be able to negotiate it successfully. There may be several revisions in the user's image of the stair as additional information about existing stair conditions is perceived. The reliability of the perceptual test will be a function of the accuracy of the user's perceptual mechanisms, as well as of the clarity of the actual images presented by the stairs themselves.

After the user has accomplished the perceptual test, and has a sufficient understanding of the stair, he is in a position to execute the appropriate motor responses necessary to enter the stairway. Negotiation of the stair is then begun. As the user enters the stair, direct sensory feedback of the prevailing stair conditions is required to test the adequacy of his perceptions. At this point, the user can be seen to exhibit marked precaution in his behavior. As the negotiation of the stairs continues, the user receives confirmation of the viability of his perceptions.

As the stair is negotiated, the user may be forced to adjust his responses to deviations by the actual stair conditions from his initial perceptual image. He may receive feedback that his motor response to the stair is inappropriate, given the condition of the stair. If the physical deviation falls within the range of the user's perceptual image, a simple biomechanical adjustment may be all that is required. If the deviations fall outside the range of the perceptual image, a perceptual retest of the situation and reselection of a more appropriate response may be needed. The user's ability to adjust to a deviation in the physical conditions appears to be related to the extent that his perceptual image is confirmed. If he is still testing his image, then he is prepared for error and can easily adjust to changed conditions. If he has received confirmation (in the first several steps) that his image is correct, then he is less likely to expect error in the stair system and be ready to respond to it. As a result, the user is less able to make the necessary behavioral adjustments in the time available.

If the user's response to, or perception of, the deviant physical conditions is extremely inappropriate, there will not be sufficient time for him to alter his behavior, and an accident will result. The accident

can be a function of 1) inappropriate response selection, 2) inappropriate adjustment to the physical condition (over or undercorrection), or 3) an inadequately tested model upon which selections and adjustments are made.

The stair use model then is a perceptual-cognitive one which assumes that the user has successfully negotiated stairs in the past and consequently has a internalized image of stair use to draw upon. A critical element of the model is the determination of the accuracy of the internalized image through perceptual testing of the physical conditions of the stair. When the correspondence between the internalized image and the actual stair conditions breaks down, the user is liable to have an accident. At this point, he must alter his behavior and his image rapidly to correspond to the changed conditions.

A critical portion of the model includes the recognition of the role of expectations. Because people have successfully negotiated stairs in the past, they may fail to realize that the present reality has changed in some way from their remembered experience. Expectations then, are the result of prior experience, and, along with sensory experience, are a prime component of the perceptual phenomenon of entering a stair system. If the expectation is tested, it is during the first moments of the encounter with the stair.

The model also implies that visual, tactile, and kinesthetic testing of the environment all occur during the first phases of stair use. Visual scanning narrows the user's range of assumptions. Next, kinesthetic and tactile testing of specific assumptions suggested by the visual perception occurs. The testing phase is interrupted when sufficiently novel stimuli are encountered. Then the testing phase must begin all over again. Finally "threshold" occurs when testing is not interrupted and the user can proceed to use the stairs with confidence in the information gained during the test phase.

One additional concept that emerged during the course of developing the stair use model was that of "orientation edge". An "orientation edge" can be defined as an abrupt change from the enclosed surroundings of a stairway to an open view of a larger space. Such changes occur, for example, as a user descends below the supporting structure of an upper floor to the first floor. Suddenly, the whole vista of the first floor opens up just at the lower edge of the upper floor. Such an edge may distract the user, causing him to orient toward events, activity, people or light within the space and away from the stair. At that time his visual attention is diverted from the stair -- and the potential for an accident is great.

Corroboration of the model involved examination of several data bases. The first was the NEISS data mentioned earlier; the second was a survey of stair users and an inventory of residential stair quality; and the third was the approximately 40 hours of videotape of stairs and stair users. These sources were analyzed for: environmental hazards (NEISS and stair inventory data); exposure to risk (survey of stair users and

videotape analysis) determination of personal, social, and environmental factors associated with critical incidents (NEISS data and videotapes); and human performance (matched sample of accident and nonaccident sequences selected from the videotapes).

In conclusion, the model of stair use and behavior suggests that there are four phases to the successful use of stairs and five for the unsuccessful use. These include: Expectation, Perceptual test, Negotiation, Adjustment, and Accident. Table 4 displays a flow chart of some of the different processes occurring during the entry to and use of a stair. Further consideration of the model suggests a number of processes involved in the course of stair use. These include:

- accommodation of the user's <u>Intentions</u>
- focus of the user's <u>Attention</u> upon the stair
- <u>Detection</u> of stair conditions
- <u>Proportion</u> of stairs to accommodate user needs
- assurance of adequate <u>Serviceability</u>
- provision of adequate <u>Traction</u>
- elimination of critical points of <u>Impact</u>

These processes are listed in the order that the user will perform or encounter them, as well as according to their relative contribution to stair safety. By considering each of these points, a designer can ensure that the user will be able to use the stair system more safely. The intersection of these processes with the relevant Guidelines is given in a matrix in Appendix A.

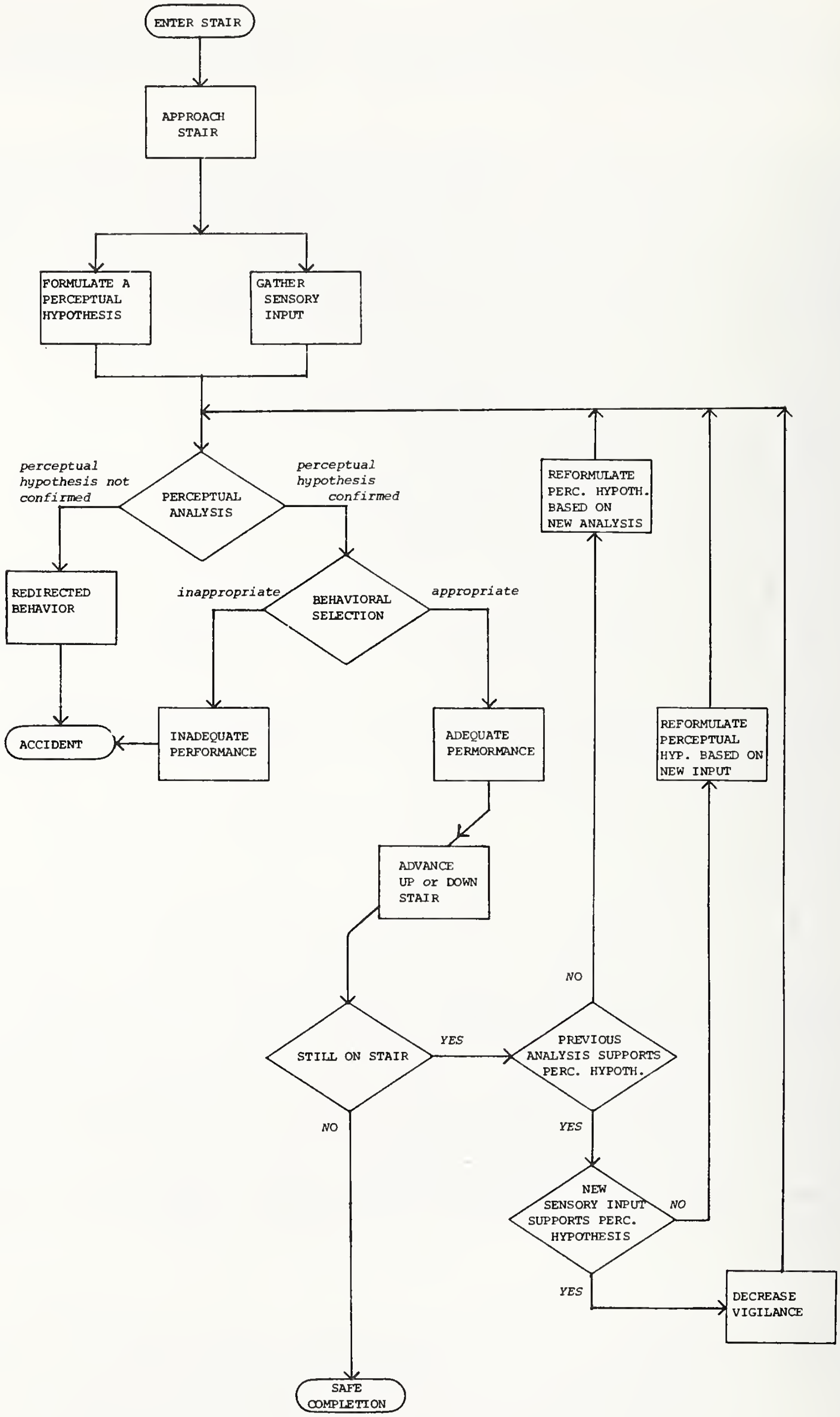
1.2.5 Data Collection

1.2.5.1 Videotapes

While the model provides a framework for assessing stair use and behavior, its predictions should be assessed experimentally, before design recommendations are made. As noted earlier, the review of the codes, literature, and the NEISS in-depth investigations also failed to assess the components of normal stair use behavior or the design-related causes of stair accidents. Because an exploratory analysis of stairway-use data at Washington National Airport and at NBS had demonstrated that film and video recordings were successful methods for collecting stair use data, a research program of extensive videotaping and film recording was initiated at NBS. This program was intended to examine the processes involved in stair use and to refine and support the model of stair use behavior.

Data were collected on videotape to test specific implications of the stair use and behavior model through the systematic analysis of behavior in specified stairway settings. A particular objective was the determination of the importance of various perceptual cues as well as an understanding of the features of the stairway environment addressed by stair users. In addition, the behavior of special user groups, such as children and the aged, was of interest. Finally, behavior was observed

TABLE 4 - FLOW CHART OF STAIR SAFETY MODEL



to identify unanticipated behavior patterns occurring during stair use. Videotape and film were selected as the media for recording stair use data for two reasons. First, they offer the capability for repetitious observation of a particular sequence of behavior and for slow-motion playback. Second, they allow the researcher to return to a given set of data to verify new findings which might emerge elsewhere.

Data were collected in public settings, rather than residential, to minimize the distraction to the stair users during the recording sessions. In addition, the camera was less obtrusive, the traffic volume was greater, and the population variety was larger in public spaces. Nevertheless, the basic principles of stair use are believed to be similar for both public and private settings. The residential stair situation does differ in that the user should be more familiar with the stairs and the attendant hazards. Thus the public setting could represent a "worst case" analysis wherein distraction might play a larger role than the very familiar residential situation. The need to collect data on a variety of population types led to the selection of four sites for data recording. These included a shopping center and library with a general population sample, a kindergarten/first-grade complex with young children, a classroom situation with adolescent children, and hot lunch programs for elderly residents.

During the investigation of stair accidents, over 40 hours of videotapes were collected. The users included preschool children, the elderly, adolescents, and adults. About a dozen accidents (without serious injury) were recorded, along with approximately 120 noticeable missteps. In general, the analysis of the tapes indicated that distractions and deceptions related to the architectural environment were a major cause of accidents and missteps. These distractions included the appearance of stair materials, shadows and glare on tread surfaces, relative differences in lighting between the stair and surrounding areas, patterned surfaces, optical illusions, and the abrupt presentation of interesting vistas (orientation edges) at critical points near the top or bottom of a flight of stairs.

1.2.5.2 Detailed Analysis of the Videotapes

A detailed analysis was made of subjects on the uppermost flight of a rather complex stair in a shopping center to determine the orientation and placement of the subjects' heads and limbs as they descended the stair. This analysis revealed that just before descending, subjects appeared to perform a "perceptual" test in which a detailed visual and tactile inspection was made of the stair. Close observation of head orientation and foot position suggested that as subjects approached the stair they displayed behavior that could be interpreted as either cautious or assured. It appeared that a distinct pattern of visual and tactile testing occurred for some subjects which could be interpreted as "cautious". This pattern was typically associated with successful stair use. Thus, the "cautious" subjects looked at the stair, and then exhibited a characteristic foot pattern or "signature", as they stepped onto the stair. "Assured" subjects who failed to look at the stair

or demonstrate the foot signature of the "cautious" subjects often had missteps or accidents later. When a limited examination was made of head orientation and foot signature for a small group of users, it appeared that looking down on the step immediately prior to actual descent seemed to be more predictive of stair negotiation success than looking down on the actual step down. These findings cannot be confirmed statistically because of the small number of occurrences. Nevertheless, they suggest some aspects of user behavior that may be important for avoiding stair accidents.

The tactile phase of perceptual testing was found to be characterized by distinctive foot patterns. Detailed data analysis indicated that three foot movement patterns, occur typically during the approach to and use of the stair (See Table 5). The patterns vary in the level of confidence and certainty exhibited by the users. Further analysis of the head and eye patterns revealed that the majority of users looked down on the first two steps of a stair. Furthermore, about most of the users exhibited the w-foot signature on the initial step down as well. The presence of the w-foot signature was used as an indicator of tactile testing which occurred extensively on the initial step down. Visual testing, as measured by a downward position of the head, appeared to occur just before the tactile (foot) testing. Yet, although visual testing precedes tactile testing, both appear to peak during the transition from level walking to descent and then decline afterward during a successful stair use. Failure to use visual or tactile testing appeared to contribute to the likelihood of having an accident.

TABLE 5 - CHARACTERISTIC FOOT SIGNATURES

Signature	Foot Movement Pattern	Place of Occurrence	Apparent Level of Confidence
✓	Toe - Down swing Heel - Down	Level Walking	Assurance
w	Toe-down to partially horizontal to toe-down to horizontal	1st, 2nd, 3rd, steps of descent - will reappear after misstep in any portion of stair	Uncertainty
v	Toe-down and return to horizontal (tiptoeing)	Later phases of stair descent	Assurance

1.2.6 Critical Incident Analysis

Templer, Mullet, Archea, and Margulis (1978) analyzed selected segments of the NBS videotapes to determine if there were behavioral characteristics and design elements which separated stairs on which missteps occurred from those on which no missteps occurred. Missteps were studied rather than accidents because very few actual falls were recorded on videotape. Yet, it was believed that a misstep was a precursor to a fall that was prevented. As such, an assessment of missteps was expected to provide valuable information about both stair design and user behavior characteristics that can accompany stair accidents.

In the analysis of stair user characteristics conducted by Templer, et al., (1978) the authors focused upon videotapes which had already been edited for stair incidents. A stair incident was defined as a case where a user fell, tripped, slipped, or experienced an event that might have resulted in a fall. The analysis of stair design characteristics focused on a representative sample of videotapes, in an attempt to determine the frequency of stair incidents for each flight. The details of the sampling procedures are given in Templer, et al., (1978).

In the critical incident analysis, nearly 60 variables were studied in three categories: stair user characteristics, user behavior characteristics, and stair environment conditions.

The stair incident analysis focused on a relatively small number of incidents (105) on a total of 43 flights. Because of the small number of incidents per flight, only limited inferences can be drawn from the analysis. Nevertheless, a number of user behavior characteristics were found to be associated with stair incidents with some degree of frequency. These characteristics included such variables as: age, length of clothing, speed of movement, gait, whether objects were carried, user group size, type of handrail use, reactions to other stair users, and need for assistance in stair use. In addition, the tapes were analyzed to determine what dynamic effects, if any, occurred. This analysis demonstrated that for a number of the incidents, there was a noticeable change in behavior just before the incident occurred. Table 6 summarizes several behavioral variables and the number of times a change in each of these occurred. For the 105 incidents, a change in user behavior immediately preceded 43 incidents. These data suggest that a change in behavior may well precede a stair incident, and that many of these changes appear to involve alterations in a user's attention.

TABLE 6. NUMBER OF CHANGES IN BEHAVIORAL VARIABLES UNDER USER CONTROL. CHANGE OCCURRED AS USER MADE THE TRANSITION FROM A "SAFE" STEP TO THE ONE ON WHICH THE ACCIDENT OCCURRED.

Behavioral Variable	Number of changes
Stair channel	7
Attention: facing	2
direction	12
elevation	21
Apparent object of attention	20
Handrail use	9
Type of handrail use	9
Reaction to other stair users	12

The second portion of the analysis conducted by Templer, et al., (1978) examined the relationship between stair incidents and environmental factors. Templer, et al., (1978) were able to isolate characteristics of stair design that seemed to be related to an increased likelihood of an incident. These design characteristics included the following: steps per flight, stair width, riser height, tread width, nosing type, step surface, view from the stair and the presence of orientation edges.

Table 7 summarizes the characteristics of high and low risk stairs. An analysis of the number of environmental changes from step to step indicates that the high risk stairs (as defined in Table 7) have more such changes. This association suggests strongly that uniformity in stair characteristics is desirable - and should decrease the likelihood of an incident. Additionally, a greater number of orientation edges were associated with the higher risk stairs.

In conclusion, Templer, et al., (1978) defined a number of behavioral variables and design characteristics that appeared to be associated with an increased number of stair incidents. The behavioral variables include such elements as age, clothing length, heel types, gait, and group dynamics. In addition, sudden alterations in dynamic user behavior often were found to precede a stair incident as might be expected from the stair use model. Similarly, design features which appeared to be related to higher risk stairs were also identified. These included - fewer steps, wider flights, lower treads, narrower treads, absence of nosing projections, polished tread surfaces, views and orientation edges. Templer, et al., (1978, p. 15) concluded that: "All of the findings point to the need for homogeneity of design of the stair environment from step to step. Not only should each step match its neighbors in terms of dimensions, shape, etc., but the surrounding environment that can be perceived from each step should also match its neighbors."... "Safety is also related to unchanging behavior as the users walk from step to step on a stair, but obviously, it is not possible to mandate safe responses to the environment."

1.2.7 Survey and Inventory of Residential Stairs

Carson, Archea, Margulis, and Carson (1978) conducted a survey of stairway use and behavior as well as an inventory of existing residential stairways for a sample of 253 residences in Milwaukee County, Wisconsin. Direct field observations and physical measurements of stairways were made in a subsample of 54 residences.

The study involved an inventory of the number, type, and quality of stairways in a sample of residential dwellings. Using a questionnaire, Carson, et al., also surveyed the residents of these dwellings about their stairway use and behavior. In addition, a statistical analysis was made of the physical and behavioral variables associated with all the stairway accidents reported in the sample.

Data were collected by means of phone samples and mail questionnaires, personal interviews, direct observations, and field measurements. The first two methods were used for the whole sample of 253 residences; the latter three for the subsample of 54 residences. Four general types of data were collected:

(a) <u>Demographic and background</u> data, including such variables as age, income, building type, number, and sex of family members, etc.

TABLE 7 - CHARACTERISTICS OF HIGH AND LOW-RISK STAIRS

Variable	High-Risk	Low-Risk
Steps	2, 3, 9 steps	18, 24 steps
Width	60 in., 61 in., 66 in.	49 in., 59 in. wide
Riser Height	less than 6-1/4 in.	more than 6-1/4 in.
Tread Depth	12 in. or less	12 in. or more
Nosing Projection	No	Yes
Stair Surface	Polished terazzo	Other
Lateral View Ascent and descent	Rich view* on one side	Open 1 side or rich view both sides
Overhead View Ascent and descent	Open above (open plus rich view* - ascent)	Closed above
Orientation edge - descent	2 or more changes	1 or less changes
Position of step in stair	first 3 or last 3 steps - 70% of accidents	Middle

* "rich view:"--connotes a view with many people or great variety in environmental conditions which can attract the stair user's attention

(b) Physical inventory including the general configuration and condition of all inside and outside stairways, number of users, structural and covering materials, etc.
(c) Behavioral survey including reported stairway habits of the respondents (and their families), reported stair accidents in the respondent's home, and record of the respondent's own stairway use at home.
(d) Site measurements and photographs, including the number of risers, height, width, headroom, tread and landing finish, light levels, coefficients of friction, etc.

The inventory of stairs revealed that there were a total of 1755 flights with one or more risers among the 691 stairways. For the most part interior staircases were made of wood covered with linoleum or tile, paint or varnish, or carpeting. Exterior stairs were predominantly exposed concrete. See Table 8.

When the respondents were questioned about the need for stairway repairs, 21% of those responding indicated the need for repair. These ranged from small repairs (22%) to full replacement (78%). Full replacement items included tread materials, handrails, and lighting. Users were concerned about stair safety but displayed conflicting opinions about improving specific hazards or conditions on the stairs. For example, despite the concern they expressed about handrails, respondents tended to overlook the fact that 1/3 of the stairs in the site sample had potentially hazardous, loose handrails.

The next portion of the survey dealt with the occupant's stair habits. Over half the respondents reported problems with footwear including wearing slippers and clogs, going barefoot, or wearing only stockings. Other problems included wearing long clothes (20%) and failing to use the handrail (39%). For the most part, respondents failed to report objects on the stairs even when photographs revealed their presence.

The survey also attempted to determine the extent of stair use. Although the total amount of stair use was proportional to the amount of time spent at home, the rate of use was related to the time of day. The greatest rate of stair use, for example occurred in the morning before 10:00 AM. The number of stairways appeared to be related more to use than any other variable.

The study by Carson, et al. also included an accident event analysis. There were 170 accident events reported in three categories. See Table 9. These included "serious" accidents, in which a true fall requiring first aid and medical attention was recorded; "moderate", in which lacerations, bumps, or contusions which did not require medical attention occurred; and finally "incidents" in which a slip or fall occurred without serious injury. Accident events were reported as occuring "recently", "within the past year", or "less recently but within the past 5 years".

TABLE 8 - RESIDENTIAL STAIR CHARACTERISTICS

	Interior	Exterior
Composition	98% wood	76% exposed concrete
Covering Material	30% full or partial carpet moderate friction 26% painted/varnished wood low friction 30% tile/linoleum low friction	
Riser/tread dimension irregularities	46% - 1 in. or more between shortest and longest riser/tread dimension	
Mean riser height	= 7.7 in.	
Mean tread depth	= 11 in.	
Handrails	30% loose, splintered, broken	
No handrails	23%	
Mean height	31" (SD = 5.0 in.)	
Width between	35" (SD = 3.1 in.)	
Number of risers	75% - 11-15 risers	
Lighting - field	26% have glare (defined as a difference of 20 foot-candles between tread and wall illumination) 83% of stairs - light levels below 10 footcandles	
Low headroom	59% of stairs	
Orientation edge	52% of stairs	
Low headroom plus Orientation edge	40% of stairs	

TABLE 9 - SUMMARY OF ACCIDENT DATA SHOWING EFFECTS OF DIFFERENT VARIABLES

NAME OF VARIABLE	HAS EFFECT BY ITSELF	SHOWS AN INTERACTION WITH THE FOLLOWING VARIABLES
DWELLING UNIT:		
AGE OF STRUCTURE	NO	TYPE, HAZARDS
TYPE OF STRUCTURE	NO	# STWYS, HAZARDS, AGE STR.
RENTER/OWNER STATUS	NO	
VALUE OF HOME	NO	NO INTERACTION
MONTHLY RENT	NO	NO INTERACTION
NUMBER OF STAIRWAYS	YES	HAZARDS, TYPE OF STRUCT.
PERSONAL:		
RESPONDENT AGE	NO	SEX, USES/HR, STWY HABITS
RESPONDENT SEX	NO	RESP. AGE
USES PER HOUR	NO	STAIRWAY HABITS, RESP. AGE
USES PER DAY	YES	NO INTERACTION
STAIRWAY HABITS	YES	RESP. AGE, USES PER HOUR
STAIRWAY:		
NUMBER OF RISERS	NO	NO INTERACTION
RISER-TREAD DIMENSIONS	TREND	NO INTERACTION
LIGHT LEVEL	NO	LIGHT GRADIENT
LIGHT GRADIENT	NO	LIGHT LEVEL
TREAD MATERIALS/FRICTION	NO	NO INTERACTION
NUMBER OF MATERIALS	NO	NO INTERACTION
HANDRAIL PRESENCE	NO	SEVERITY OF ACCIDENT
LOCATION (B-1, 1-2, etc.)	TREND	CONFIG, IRREG, WINDERS
DIMENSIONAL IRREGULARITY	TREND	LOCATION
CONFIGURATION	TREND	LOCATION
PRESENCE OF WINDERS	NO	LOCATION
LOW HEADROOM	TREND	ORIENTATION EDGE
ORIENTATION EDGE	TREND	LOW HEADROOM

[1] Source, Carson, et al., 1978.

Data for the "moderate" and "serious" accidents were found to compare well with the NEISS distributions for different age groups. The NEISS distributions, of course, did not cover the "incident" data, but these were included in the Carson, et al. report because they pointed to important stairway safety factors.

When the demographic variables of renter-owner status, value of home, monthly rent, and sex of respondent were compared with stairway accidents, no significant relationships emerged. A more detailed level of analysis revealed that significantly more accident events did occur in single-family homes, and among people in the 25-34 age group (who used the stairs more frequently). Nevertheless, the broad demographic categories did not serve well as predictors of stair safety.

An examination of physical factors related to stair problems revealed some interesting trends (see Table 10). Rate of accidents, which was found to be related to exposure to (or use of) stairways, was not found to be related to the number of risers. Within the range of riser-tread dimensions compiled from the site measurements, the number of accidents was not found to be systematically related to any of the recommended dimensions. There was a tendency, however, for the least preferred set of dimensions to have a greater number of reported incidents. There was also a tendency for more accidents to occur for low light levels with steep lighting gradients. This interaction does not reach significance because of the small number of events recorded. A study of the effect of variation in light gradient would require a larger number of stair incidents and a more precise analysis of the effects of visual adaptation. No correlation was found between the different stair tread materials and accident rates. Furthermore, "slipperiness" or "friction" was not found to be related to accident rates. Carson, et al. comment that accident rates do not appear to be determined primarily by the friction characteristics of ordinary materials. Stair surface slipperiness, however, may be a factor when it is very low, such that shoes can catch in the stair material, or when it is very high. In addition, the soles of the user's feet may be slippery particularly if he is wearing only stockings or socks.

Although the respondents repeatedly stated the need for more handrails, the absence of handrails was not found to be related to an increased accident rate. In fact, the data show a trend toward an increased number of accidents when handrails <u>are</u> present. A more detailed analysis revealed that critical incidents occur five times as frequently on stairs with handrails. Yet, the frequency of moderate-to-serious accidents was about the same for stairs with handrails as for stairs without handrails. Carson, et al. suggested that the presence of handrails can reduce the severity of a stair accident and that the lower frequency of accidents on stairs without handrails may be due to greater precaution exercised by the user. They also found a non-significant trend toward a reduced accident rate for stairs with more regular handrail heights.

Other physical variables which were compared against accident rates, included configuration, location, riser-tread irregularity, and the use

TABLE 10 - PHYSICAL FACTORS WHICH TEND TO BE RELATED TO STAIRWAY ACCIDENTS

Factors associated with High Accident Rates

- ° Riser/tread dimensions such that stair is steep
- ° Location of stairway between first and second floor
- ° Larger dimensional irregularities
- ° More turns on stairways
- ° Low headroom
- ° Orientation edge
- ° Presence of handrails associated with more frequent but less severe accidents

Interactions Between Factors

- ° Presence of both low headroom and orientation edge
- ° Location of stairway and stairway configuration
- ° Location of stairway and dimensional irregularity
- ° Location of stairway and presence of winders

Behavioral Variables

- ° Higher hourly rate and age of user (those under 45 who average more than 2 uses per hour)
- ° Total daily use - directly related to accident event
- ° Large number of careless or casual habits

of winders. In general, stairs located between the first and second floors demonstrated higher accident rates than stairs in other locations. (Of course, such stairs are used more frequently). Stairways with 180° turns had more accidents than other stairways, particularly when these stairs were located between the first and second level of the house. Irregularity in riser-tread dimensions was found to be related to increased accident rates for the total sample, though not for the site sample. Again, stairs with irregularities between the first and second floors showed a higher number of accidents. The presence of winders between the first and second floor appeared to contribute to increased number of accidents. Because winders contribute to both increased turns and stair irregularities and because they appear more frequently on stairs between the first and second floors, Carson, et al. suggested that winders create various hazards which lead to increased stair accidents. When both low headroom and orientation edge occur together, there is an increase in the number of accidents for the stair - although there does not appear to be an increase when these occur separately.

Thus, the reports by Carson, et al., and Templer, et al., indicate that there are certain design features which tend to be related to greater numbers of accidents on stairs. Chief among these are irregularies within a flight, in terms of variations in dimensions, number of turns, number of steps, presence of headroom, and the like. In addition, the occurrence of distractions on or near the flight of stairs appears to contribute to the likelihood of missteps, and potentially, to accidents on stairs. In addition, observation of stair use and behavior on the NBS videotapes indicates that visual and tactile testing is used upon a person's entrance to a stairway. Thus, these reports provide some insight into both normal stair behavior and into the factors which can contribute to a stair accident. They indicate further that there is a certain validity to the stair use and behavior model - which still requires additional experimental validation, but which is useful for predictive purposes.

1.3. SUMMARY OF STAIR USE INFORMATION AND MODEL

In conclusion, consideration of the data analysis and the model suggests that stairway systems be designed to accomplish the following four objectives:

- ° facilitate accurate hypothesis testing
- ° expedite accurate behavior selection
- ° ensure adequate performance
- ° protect users from injury due to failure in testing, selection and performance

Elements of the stair system should be designed to enhance the perceptual testing process. Features of the environment should force the user

to pay attention to relevant stimuli and to facilitate discrimination among necessary, but competing cues. Thus, false, misleading, or distracting cues should be avoided, as should sensory or information overload.

In the preceding sections, behavior on stairs was observed under normal, non-emergency conditions to determine some of the perceptual and biomechanical processes involved in successful stair use. There was a concern with judgmental errors which might be triggered by the attributes of the stair components themselves or by the spatial and luminous characteristics of the entire stairway. Thus, the focus was upon environmentally triggered human errors which could result in stair accidents.

Although many stair accidents can be triggered by errors or inattention on the part of the user, it is rare to find a stair accident in which the user makes an error that cannot be linked to a distraction, irregularity, or deception built into the surrounding environment of the stairway. While some of the hazards are obvious, many of those which contribute to serious accidents can be quite subtle and may, consequently, escape notice even after the accident has occurred. An accident occurs only under a particular combination of physical and personal circumstances. Although such a combination may occur infrequently, the fact that no accident has occurred on a particular stair should not be taken as evidence that it is hazard-free.

In addition, because stairs are so familiar to the user, subtle hazards may often be overlooked. Since stairs involve a special form of locomotion different from level walking, people must make a definite change in their walking behavior upon entering a stair, and again when resuming level walking. Yet, stair use is a common behavior, with which most person are familiar. This understanding of stair use as a special, yet extremely familiar (in some ways dangerously so) behavior is an essential backdrop to the investigations performed at NBS.

Facing page: *Stairs in poor repair can present serious hazards to the user.*

2. RECOMMENDATIONS AND GUIDELINES FOR STAIR SAFETY

Guidelines for improving stair safety are given in this Section. These recommendations are drawn from the overall research program carried out at NBS -- the videotapes, the critical incident analysis, the stair inventory, the literature and code review, and the review of the NEISS data. They are intended to improve the safety of new stairs and provide suggestions for the retrofit of older, potentially unsafe stairs. Throughout they recognize the importance of the user's perceptual processes and subsequent behavior, as well as the consequent need to emphasize the cues provided by the stair system.

The guidelines given in Section 2 are based upon the theoretical model developed by NBS, videotape studies of stair use, and a review of current research and epidemiological evidence related to stair use and accidents. Many of the recommendations can be supported at a "common sense" level but not at a rigorous or statistically significant level. The guidelines are intended to accommodate specific priorities generated by the model. These priorities focus on the user's relationship to the stairs, rather than on the physical details of stair construction. They include the need to accommodate the user's intentions to use the stair, and focus the user's attention upon the stair and its surroundings, thereby, enabling more precise detection of stair conditions. In addition, stairs must be proportioned to fit the user's needs. They must be serviceable and provide adequate traction. Finally, the stair and its surroundings should be designed to protect the user from further injury upon impact, should a fall occur.

Because ensuring stair safety requires attention to the physical details of stair design, the guidelines are presented according to physical design categories, rather than priorities of stair use. Thus, all the guidelines that treat stair surface characteristics, whether via improved traction or through minimizing injury during a fall, are placed together so that a designer can deal with all aspects of stair surface at the same time. Furthermore, both the physical attributes and the appearance of stair surfaces are treated. Appearance is included because the model predicts that this is an essential prerequisite for the successful perception of visual cues. The guidelines treat specific elements of the stair first and then the more general characteristics of the stairway. Thus, stair surfaces and handrails, are treated first, followed by stair surroundings. Then, guidelines for ensuring the overall structural integrity and quality of the stairs are given. Finally, guidelines for facilitating the user's approach to and exit from the stairway are provided. Thus, the guidelines are intended to provide information for ensuring a user's safety, both in terms of physical attributes and appearance characteristics, throughout the entire stairway.

The presentation of each guideline consists of: (a) a series of IF statements which indicate the safety problem at issue; (b) a THEN statement which indicates the general nature of the solution(s); (c) a suggested list of specific SUGGESTIONS for solving the problem; (d) a COMMENTARY section which provides documentation and data which support the existence of the specific stair-safety problem introduced by the IF-THEN statement; and (e) EXAMPLES and/or FIGURES of actual accidents or unsafe stair conditions which demonstrate the stair-safety problem. In addition to general safety requirements there are supplementary requirements which deal with the special needs of vulnerable user groups such as the elderly, children, and the handicapped.

2.1 STAIR SURFACES: PHSYICAL ATTRIBUTES

Among the chief concerns in the design, construction, or renovation of stairs are the provision of a proper foot-to-stair interface. This

requires a stable walking plane and adequate traction. Among the critical elements of a stable walking plane are adequacy of the dimensions of both risers and treads, as well as the uniformity of all steps. Traction is defined as the resistance provided between a walking surface and the human foot or shoe; it is a relationship established by two materials interfacing at a slip-plane. All contact surfaces must afford the user appropriate resistance to slipping for the existing configurational, climatic, and traffic conditions of the stair.

To provide a proper foot-to-stair interface, stability and slip-resistance should be adequate for the slope, climatic exposure, and traffic conditions but not so excessive as to prevent the user from pivoting or sliding his foot where necessary. There should be adequate provisions to dissipate surface moisture to prevent hydroplaning, and provisions to prevent the accumulation of ice or snow. Moisture, ice, and snow not only reduce traction but also interfere with seeing the stair.

2.1.1 Riser/Tread Dimensions

IF: the riser and tread dimensions are outside the limits of 4 to 7 in. and 11 to 14 in. respectively or...

IF: the tread depth causes the user to miss a step or take a partial step or...

IF: a stair is too narrow to accomodate simultaneous ascent and descent...

THEN: either redesign (and/or rebuild) the stairs or provide signing and lighting to make the user aware of the potential hazard and point out alternate routes where possible.

COMMENTARY - Based on data obtained from a 1969 HUD residential survey, McGuire (1971) suggested that steep, non-uniform stairs should be avoided completely, whenever possible. They "are often poorly lighted or light switches are only at one end, steps cluttered, risers too high, and treads too narrow; worn carpets and rails stopping before the last step is taken... It is obvious that uniform dimensions in risers and treads for any flight of stairs are necessary."

McGuire's data are based on a survey containing some 4,000 inquires. She found that of all stair-related accidents identified, some 22% were attributed to steep stairway and/or narrow tread design.

Harper, Florio and Stafford (1958) suggested that stairways should not be steep, that risers should be of uniform height and treads should be of uniform width. Furthermore, the sum of the height of a riser and the length of a run should not be less than 17, or more than 18 in.

The overhang should be 1 to 1-1/2 in. For interior steps, the desirable height for risers is 7 in. (six, for stairs to be used mainly by older

older or slightly handicapped persons). For exterior steps, the height of risers should be limited to five or six inches.

Templer (1974) utilized a laboratory mechanical stair treadmill to record and analyze gait rhythms generated by a range of stair conditions. When ascending stairs with risers between 6.3 and 8.9 in., and with treads from 7.7 to 14.2 in., people were found to have the fewest missteps. Stairs with larger treads were not studied. On steeper stairs, people were found to make more missteps in descent. Finally, Templer found that a minimum width of 56 in. between walls was required (with 69 in. recommended for comfort) for side-by-side passing movements.

Grandjean (1973) recommended that because the lowest consumption of energy occurred with a stair slope of between 25° and 30°, they should be constructed with 17 cm (6.7 in.) risers and 29 cm (11.4 in.) tread. This would provide a slope of 30°. Grandjean suggested that a good formula for stair dimensions is the following: $2r + t = 63$ cm (24.8 in.) where r=riser and t=tread. Obviously where space is limited, sometimes steeper slopes of 45° can be used (if the stairs will receive only limited use).

2.1.2 Internally Stable Walking Surface

IF: the carpet, mat, tile, or any other material covering any tread or landing on a given flight of stairs will slide when foot contact is made in either ascent or descent, or...

IF: any tread or landing in a given flight of stairs is covered with a loose throw-rug or mat, or...

IF: the carpet or other materials covering the treads or landing have come loose from the tread or landing itself, or...

IF: the treads or landing are covered with shag or deep-pile carpeting...

THEN: either remove, replace, or restore the floor covering material to achieve an internally stable walking surface (one that does not slip or deform within itself when force is applied).

Among the suggested ways to accomplish this are:

(a) remove the existing loose carpeting or floor covering and use the tread or landing surface underneath as the walking surface, or...

(b) restore the bond between the existing loose floor covering and the subfloor of the tread or landing, or...

(c) replace the existing loose or excessively pliable floor covering with one that is less likely to deform under loading.

COMMENTARY - Traction on surfaces has generally been considered to be a function of slip-resistance which is measured by the static coefficient of friction. In turn, the static coefficient of friction is defined as the tangent of the angle at which force must be applied to the interface of 2 surfaces in order for a slip to occur. In other words, the degree of slip-resistance required for walking is determined by dividing the horizontal component of the load by the vertical component of that load. Since the vertical component greatly exceeds the horizontal component of the forces applied by a user while ascending or descending a flight of stairs, the coefficient of friction required to avoid 'true' slipping on a stair is relatively low -- at least when compared to the requirement for level floors where the horizontal components of the forces applied can be much greater. In spite of this, many, if not most, victims of stair accidents report that they have "slipped" at some point on the stair. Yet, when the actual slip-resistance for a stair is measured, it may be such that it is almost impossible to slip on a clean and dry stair in either ascent or descent. The resolution of this apparent conflict requires some elaboration.

Most stair accidents appear to occur when the metatarsal arch of the foot (the set of bony knuckles between the greater and lesser balls of the foot) extends beyond the edge of the tread, leaving the foot unsupported, and causing the foot to roll over the nosing in descent or to "slip" off of the nosing in ascent. While such common slips seem to be the result of a slippery stair, they may actually result from improper placement of the foot upon a very much reduced surface area.

Most accidents that involve understepping or overstepping the nosing may be prevented by increasing the user's ability to detect the tread edge rather than altering the slip-resistance of the stair surface. This should increase the likelihood that the metatarsal arch will be adequately supported.

In some cases, true slips do occur. Slip-resistance is normally considered to be a relationship between the angle at which force is applied and the physical properties of various tread and shoe sole materials. Different coefficients of friction will be obtained for different combinations of materials at a slip-plane. Yet the interface between the surface of the tread and the sole of the user's shoe is not the only slip-plane involved. In fact, in a typical situation there are potentials for slip to occur: (a) between the user's bare foot and the inside of his socks, (b) between the outside of the socks and the insole of the shoe, (c) between the insole of the shoe and other layers of material within the shoe, (d) between the outer sole of the shoe and the exposed surface of the stair tread or covering, (e) between the various layers of fibers within the tread covering material, (f) between the backing of the carpet (or other material) and the carpet pad, and (g) between the carpet pad and the subfloor of the stair tread or landing. The standard measure of slip-resistance only covers one of the seven points (d) at which a true slip could occur. Furthermore, this measure presumes stability (rigidity) between the sole of the user's shoe and

his foot and between the exposed surface of the stair tread and the subfloor which is connected to the structure of the building.

Instability within the walking surface is introduced when a deformation occurs between the top or exposed surface of the tread or floor covering and the subfloor or other member that is connected to the structure of the stairway or building. For example, a thick carpet contains a bundle of fibers which can slip across each other as the weight of the user's body is placed on the uppermost surface. While the contact between the sole of the shoe and the top of the carpet might be quite stable, the slippage within the carpet (deformation), or between the back of the carpet or pad and the subfloor, can create an instability that resembles slipperinesss, but technically is not measurable as such. This internal slippage can interfere with the user's ability to monitor the relationship between his own foot movements and the condition of the walking surface. This "play" within the floor covering or between the floor covering and the subfloor gives the appearance that the treads are slippery. It can create many of the same problems for the unsuspecting user that are normally associated with slipping.

In order to minimize the likelihood that such conditions will contribute to stair accidents, it is essential that the internal stability of the walking surface be maintained. By removing the excessive layers of carpet and other materials that have been placed on top of the stable subfloor and by using that subfloor as the walking surface, the problem may be greatly controlled. By refastening these layers to the subfloor most, but not all, of the internal "play" can be eliminated or minimized. Finally, by using a tread covering that has less internal instability within itself (such as an indoor-outdoor carpet instead of a shag carpet) the problem of slippage or excessive resiliency within the material can be greatly reduced.

Based on experiments in which subjects walked up and down over a force plate on three different slopes, Harper, Warlow and Clark (1967) found that with a slope of 1 in 13, a coefficient of friction of about 0.6 is needed for safety. Slopes less than this required values of between 0.4 and 0.6.

Several investigators have noted varying numbers of stairway accidents in those cases where unstable walking surfaces were attributed to loose carpeting or other causes (Esmay, 1961; McGuire, 1971; Carson, et al., 1978). However, the existence of a causal relationship between loose carpeting, surface instability, and stairway accidents remains an empirical question.

EXAMPLES

Accident A. The victim reported that the high degree of friction which the rubber sole of her shoe exerted against the rubber doormat caused the doormat to slip thereby causing her to lose her balance. She fell down three cement steps and fractured her ankle. (NEISS)

Accident B. The victim stated that she was wearing new bedroom slippers at the time of her accident. As she was descending steps carpeted with a nylon shag carpet laid over a foam pad, she slipped on the edge of the top step, fell down 5 steps, and fractured her left wrist. (NEISS)

Accident C. The respondent's son, age 12, fell twice in the 9 months he had lived in the house. The respondent herself had also slipped twice on the same steps. In the middle of this flight, the carpet was completely detached from the wood tread underneath it and moved when walked on. While the injuries were minor, the son did hit his head in the first fall and skin his leg in the second (Carson, et al.). (The coefficient of friction measured on the top surface of this stair was higher than that needed to create a non-slip surface.)

FIGURE

Figure 2.1.2. The carpet shown here bulges over the structurally supported portion of the tread, thus creating a potentially misleading visual cue to those who view the stair from the top.

2.1.3 Tight and Uniform Tread Coverings

IF: carpets, mats, nosing strips, or other floor coverings are loose or not uniformly affixed to the treads...

THEN: secure the coverings uniformly or install new coverings.

COMMENTARY - Whenever tread coverings or nosing strips separate from the tread itself, a tripping hazard is introduced. Tile, linoleum, rubber mats, carpeting, or metal strips can produce a 'lip' where they begin to peel or role back from the tread. That lip can easily catch a user's heel or toe. Given the very small tolerances with which stair users clear the treads and nosings, even the most minor lip or edge created by loose coverings or strips can cause a major accident. This is particularly a problem at the beginning of a flight, because the user is primarily concerned with edge detection and can easily miss critical surface irregularities on the tread or nosing. It is also critical in the middle of a flight where the success of the user's initial performance on the stair generates a false sense of confidence leading to (1) even smaller tolerances for clearing nosings and (2) complete inattention to the stair treads themselves. In short, minor surface irregularities which can lead the user to trip and have a serious accident are among the most difficult characteristics of a stair to notice or anticipate. They should be eliminated wherever possible.

As evidence, Velz and Hemphill (1953) found that over 10% of the tread coverings in homes in which accidents had been reported were insecurely fastened. Esmay (1961) found that insecurely fastened tread coverings were contributing factors in 6% of the stairway accidents studied. In a study of accidents incurred by elderly persons, Chapman (1961) found that falls were the biggest cause of injury, and that some accidents were in fact caused by worn carpets and loose rugs.

Figure 2.1.2

EXAMPLES

Accident A. Although the 10 wooden steps were not carpeted, they had rubber mats tacked to them. The mats were well worn and 2 or 3 of them were missing. About halfway down the stair, the victim fell, twisted her left ankle, and fractured her left leg. (NEISS)

Accident B. When the victim was about halfway down the stairs, her heel got caught on the strip of rug she had nailed onto the steps to improve the traction. This caused her to lose her balance and she fell halfway down. She received a contusion of the left elbow. (NEISS)

FIGURES

Figure 2.1.3a. On this stair, the mats which had been fastened to the concrete treads to improve slip-resistance have delaminated due to use and exposure to the weather. The raised lips of most of the mats create very serious tripping hazards.

Figure 2.1.3b. This close-up of the same stair shows a condition where the heel could get caught during descent or where the toe of the shoe could get caught during ascent.

2.1.4 Uniform Slip-Resistance on each Tread Throughout the Run of the Stair

IF: the tread surfaces of an interior stair are substantially more slippery than the surfaces of adjoining landings and walkways made of similar materials, or...

IF: some of the tread surfaces on a stair appear to be substantially more slippery than other treads on the same flight...

THEN: either (a) refinish the tread surfaces with a fresh coat of wax or paint (using non-slip coatings only if the riser/tread ratio exceeds the maximum given in the section on configuration) or (b) restore the intrinsic slip-resistance of the tread materials by sanding, filing, or planing and filling the surface to rebuild the original surface configurations.

DO NOT: attempt to improve the slip-resistance of stair treads by adding rubber mats, pieces of carpet, adhesive abrasive strips, or abrasive edge strips.

COMMENTARY - The distribution of body forces in walking up or down stairs creates less likelihood of slipping on stairs than on level floors. Yet sudden changes in slip-resistance from tread to tread or the insufficient surface resistance of worn, smooth treads can cause problems.

Carson, et al., (1978) found no statistical relationship between the type of surface material used and accident rates. They found that lower accident rates correlated with lower coefficients of friction. These

Figure 2.1.3a

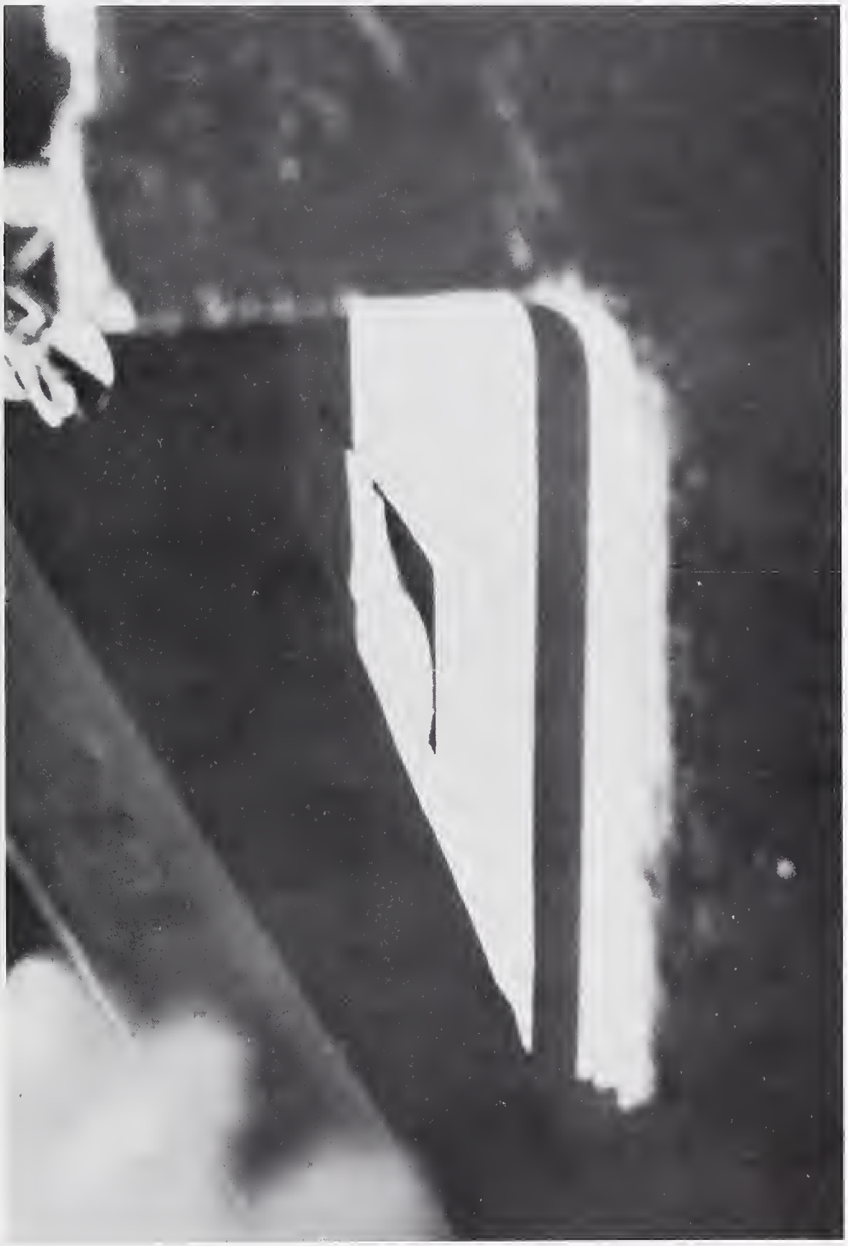


Figure 2.1.3b

investigators caution, however, that the coefficient of friction of ordinary materials does not appear to be a primary causal factor determining accident rate (except in extreme cases, e.g., ice, or the opposite condition in which the foot is constantly locking against the surface material).

McGuire (1971), who reviewed some 4,000 inquires in a 1969 HUD survey, found that some 30% of all stairway accidents reported were attributed to slippery treads. When Miller and Esmay (1961) investigated the slip-resistance of various stair tread coverings, they determined that rubber mats and varnish coatings were each twice as hazardous as paint coatings or bare wood surfaces.

Harper, Warlow and Clark (1967) found that the coefficient of friction was related to stairway slope. For slopes approximating 1 in 13, a coefficient of 0.6 is needed for safety. For smaller slopes, 0.4 through 0.6 may be adequate. These investigators found that in ascent, there is extremely little risk of falling from a "slip". In descent, however, the risk might be quite high. Finally, Harper, et al., suggested that high-friction nosings might be useful in reducing slips in the case of stairways with steep slopes, but hazardous where the slopes are small.

Finally, Esmay and Segerlind (1964) suggested that the forces exerted on stairs are rarely large enough to cause a person to slip (assuming conventional surfaces and materials).

2.1.5 Slip-Resistance on Stairs Exposed to Precipitation, and on Surfaces that Dissipate Moisture on Outdoor Stairs

IF: stairs are exposed to precipitation...

THEN: use nonslip finish or refinish with an abrasive paint or similar application, and/or...

provide an absorbent or well-drained tread surface to prevent the beadlike formation of rain water (to prevent hydroplaning of the shoe sole on the tread).

COMMENTARY - Although problems associated with the occurrence of slippery surfaces were treated in considerable detail in Guidelines 2.1.3 and 2.1.4, Sigler (1973) found substantial differences in slipperiness between wet and dry surfaces, with the dry ones providing the most traction. However, no statistical analysis of data appears to demonstrate a correlation between surface wetness and stairway accidents.

EXAMPLE

Accident A. The approach to the porch consisted of a 2-step, wide stairway with no handrail. The 3-ft.-wide cement walk had a crack with one side 1-1/2 in. higher than the other side. The steps which were

made of smooth cement with a coat of gray paint, were very slick when wet. The victim suffered contusions of the left side and lower mid-back.

2.1.6 Slip-Resistance on Long or Sloping Treads and Sloping Landings

IF: the depth of the tread exceeds 14 in. and/or...

IF: the stair treads slope downward in the direction of the nosings or...

IF: the landing adjoining a stair slopes...

THEN: finish the treads or landing with an abrasive finish (such as an abrasive paint) to increase the coefficient of friction.

COMMENTARY - Problems associated with the occurrence of slippery surfaces were treated in considerable detail in Guidelines 2.1.4 and 2.1.5. As length of the user's stride increases, the horizontal component of the force applied increases, and the potential for a slip increases. Although no data or analysis is available which establishes a causal relationship between slipperiness of long or sloping treads or landings, and stairway accidents, the potential for a hazardous situation should be assumed to exist.

2.1.7 Slightly Rounded Nosings

IF: the exposed edges of the nosings on a given flight of stairs are sharply squared-off, with no bevel or curvature, or...

IF: the exposed edges of the nosings are coarsely textured, forming rough or jagged edges...

THEN: refinish or replace the nosing-tread member so that the edge of each is even-textured and slightly curved in cross-section, with a radius between 1/4 in. and 1/2 in.

Among the suggested ways to accomplish this are:

(a) replace each nosing with one having the required edge characteristics, or...

(b) (for wood treads) round the nosing section by planing, filing, and sanding, making certain that the degree of curvature on all nosing edges is uniform.

DO NOT: apply a metal, plastic, or rubber nosing strip, or a new stair runner or mat to achieve the effect of a rounded nosing.

COMMENTARY - A common type of accident on stairs involves tripping on the top of the riser or nosing during ascent, and then falling forward. The typical reflexive response to such a fall is to thrust the hands

forward to brace oneself by grabbing the nearest tread or nosing. Ordinarily this maneuver is successful, and such accidents usually do not result in serious injury. However, in many cases parts of the body do contact the nosing edge with considerable force. To minimize injuries in such cases, it is essential that the edges of each nosing distribute those forces as widely as possible and minimize the possibility of breaking the skin upon impact. Therefore, the slightly rounded nosing can minimize the likelihood that a minor misstep will result in a serious injury.

It is important, however, that the nosing be an integral part of the tread. It should not be applied to an existing surface, because it could separate after prolonged use. The curvature of the edge should not be too great, so that the likelihood that the user's foot will bear on a sloping surface, rather than a level one is reduced.

Empirical attention has been focused on the provision of tread nosings by Gowings (1961) and Fruin (1971). The latter investigator, on the basis of his extensive observations of pedestrian behavior, suggested the use of rounded nosings. While there appears to be no empirical basis for the recommended nosing dimensions or radius specifications, common usage has shown these to be most appropriate.

2.2 STAIR SURFACES: APPEARANCE

The proper and safe use of stairs requires that users be able to adjust their behavior to meet changing demands. The ability to make rapid and adaptive adjustments depends, in turn, upon the quality of the users' perceptions of key stair components. A critical issue concerns the correspondence between the apparent and actual characteristics of the stair components, and their relationships to one another. An objective should be to provide the user with all the cues necessary to correctly detect the prevailing condition of the stair at the time of its use. The human error associated with detection is the "failure to identify" a hazardous characteristic of the stair. The environmental defect associated with detection is a "deception" that is built into a stair in a manner that increases the user's susceptability to misreading the characteristics of the stair. Since people will generally be able to compensate for unusual or hazardous conditions of which they are aware, ensuring the detection of the hazard is important.

The tread surfaces themselves provide many important cues. Accordingly, care should be taken when designing their appearance. It is essential that: (1) a complete, correct, and consistent pattern of cues that emphasizes and corresponds to the conditions actually prevailing on the stair be available to the user; (2) all colors, edges, lines, alignments, planes, patterns, and textures interact to produce a "true" representation of stair surface conditions; and (3) stair surfaces be free from permanent design features and transitory qualities that could serve to confuse the user.

2.2.1 Visibility of Tread Edges

IF: any users are unable to clearly distinguish the edges of each tread when the flight is viewed from the top landing under normal use conditions, and particularly...

IF: users who are elderly or who have poor eyesight experience a blurring of the edges which distinguish the separate treads as they descend the stairs, or...

IF: the stair treads are finished with a surface material or covering that has a distinct geometric, pictorial, floral, or randomized pattern which is visually more pronounced than the edges of the treads themselves...

THEN: replace or refinish the tread surfaces and nosings, and place an illumination source so that a clear visual distinction is provided between planes representing each stair tread including the top tread or landing when seen from above, and so that "visual noise" created by surface patterns is eliminated.

Among the preferred ways to accomplish this are:

(a) provide a uniformly textured, plain-colored surface on each tread throughout the run of the flight and...

(b) provide a relatively directional light source which provides illumination for each of the stair treads from a point of origin above the lower landing, and/or...

(c) mark the edge of each tread with a single built-in or painted stripe which (1) contrasts noticeably with the remainder of the tread in color and texture, (2) extends not more than 1-1/2 in. into the tread from the nosing edge, and (3) is flush with the remainder of the tread surface. Do not add a nosing piece or glue-down abrasive strip which protrudes above the tread surface to any degree.

<u>COMMENTARY</u> - A critical requirement for successful stair negotiation is that the user's metatarsal arch must be thoroughly supported by the tread. In order to assure that the foot will be adequately supported, the user must be able to detect the precise location of the tread edge prior to stepping upon the tread. This requires reliable cues which facilitate the visual detection of the edge of each tread. The accuracy of this visual analysis will depend, in part, upon how much visual information the user can process or sort in a very brief increment of time. For descent, the combination of surface and edge cues must produce a figure-ground relationship in which the tread edge appears as the figure, and the lower tread as the background. For ascent, the edge must be clearly set-off from the abutting tread and riser.

An important impediment to correctly perceiving a separation between tread surfaces when the stairs are seen from above is the optical illusions created by prominent two-dimensional patterns and coarse three-dimensional textures on the tread surfaces. It is also possible to perceive the tread edge as part of the surface pattern when the pattern has stripes running parallel with the nosing, a common feature of many non-slip tread designs. In such cases, it is difficult to quickly determine which strips represent the tread edges.

With other patterns less likely to produce a false edge, the visual prominence of the pattern may create a high degree of visual noise against which the detection of the tread edge becomes difficult. This optical masking appears when the elements in the pattern are distributed randomly, producing a very busy visual surface in which elements from two adjacent treads can be seen momentarily as components of the same tread. Separate treads may appear to merge into common patterns, so that they take on the appearance of a continuous ramp-like surface in which the edges are lost to the eye.

Coarse three-dimensional textures on stair treads can also create optical confusions. For instance, a random array of small stones in an exposed-aggregate concrete stairway, or the tangle of fibers in a shag carpet, can trigger the same visual fusion across tread edges that has been described for random two-dimensional patterns. Successive tread edges of such coarsely textured materials can appear to merge and create the illusion of a continuous surface. As a result, plain-colored, fine-grained, uniformly-textured tread coverings should be used to maximize the reliability of visual cues needed to detect the edge.

Unfortunately, the absence of visual chaos on the tread surfaces will not, by itself, assure accurate edge detection. Even a uniformly patterned and textured tread surface can appear to blend into the next tread under certain lighting conditions. Consequently, it is also necessary to accentuate the visibility of the edge itself. If the primary source of illumination provided for each flight is relatively directional (originating from a single source, but not a spotlight), and originates above the lower landing; and if the top of the nosing of each tread is slightly rounded, a highlight will appear at the edge of each tread as it is viewed from above. This "modeling effect" is further accentuated on a carpeted stair by the spread of the fibers as they bend around the nosing, creating a detectable change in surface texture. Together, the combination of uniform surfaces, directional lighting, and rounded nosings provides the most reliable cues for detecting the edges of stair treads.

There are several measures that can be taken to improve the visibility of each tread edge. Two of the most common are (a) the use of a single contrasting strip at or near the edge of each tread and (b) the use of different colors on alternate tread surfaces. Both have their drawbacks. The single painted strip may tend to wear off after prolonged use. Although metal edges or adhesive strips applied to the nosing or tread surface may aid visual detection, they can loosen after a period of use.

The most effective solutions to the visual detection problem may not be these "applied" remedies, but rather may be minor adjustments in surface, lighting, and nosing characteristics which interact to give the user all the cues needed to determine where to place his foot.

The stair safety literature contains numerous anecdotes describing accidents which have been attributed to deceptive patterns on stair treads. In 1942 Howell reported that "stairways covered with razzle-dazzle, camouflaged carpets are particularly bad." He cites a California court case of that era (Twohy vs. Owl Drug Company) in which it was decided that where such camouflage effects exist on stairs, negligence exists. Although Howell heralded this as a landmark liability decision, acceptance of the notion that visual deceptions are a leading factor in stair accidents has been slow to develop.

Mowery (1968) reported that, in a New York City railroad station, users experienced difficulties with a stair which had non-slip metal treads consisting of "a series of grooves or even lines parallel to the edge" of each tread. According to Mowery, persons descending this stair who had bad eyesight or wore bifocals were often confused as to which line was the step edge. Some 1414 falls, many resulting in serious injuries, were reported within a six week period. After replacing the original tread surface with a material of non-slip design and without parallel grooves, no accidents were reported over a three month period.

In an experimental study Pastalan, et al., (1973) found that subjects wearing glasses which simulated the visual impairments common in old age reported considerable difficulty in discriminating "risers and treads while going down a flight of stairs, particularly when the stairs were carpeted with a floral print carpet...." The investigators also reported that similar colors, particularly in the blue-green range, were almost impossible to distinguish, and that "when two intense colors such as red and green bounded each other... the boundary became visually unstable because the intensity of the colors seemed to overlap and as one focused on the boundary it appeared to shift." In sum, there is some evidence in the literature to suggest that stair users, especially the elderly and persons with poor eyesight, have considerable difficulty in detecting tread edges under certain conditions, and that this difficulty can lead to accidents.

During the analysis of the NBS videotape data, it was noted that users who were descending one particular stair seemed to be moving in slow motion. Closer examination revealed that the combination of randomly distributed pockmarks in the travertine marble treads, uniformly distributed lighting, and sharply squared-off nosings made it difficult to detect the edges of the treads when looking from above. It is possible that the slow rate of descent may have resulted from the increased time needed to locate each edge.

In an informal pilot study conducted by Pastalan, et al., subjects took almost twice as long to negotiate the first step in a flight of terrazzo stairs when they wore the experimental glasses than when they did not.

Thus, the inability to detect the edge may be a function of both the visual capabilities of the user and the appearance of the tread.

EXAMPLE

Accident A. All the floors and stairs inside the respondent's apartment were covered with a light colored sculptured rug, which made it difficult to distinguish the tread edges. The lighting hit the stairway so that the edges of the steps did not stand out (Carson, et al., 1978). The respondent lost her balance, fell down, and pulled a muscle. Her husband also fell down the same stairway.

FIGURES

Figure 2.2.1a. The very busy pattern on this carpeted stair makes it difficult to detect the edges of the tread. Note that the center line of the elements in the carpet pattern is not parallel with the edge of the nosing at the top of the stair - a deception in the midst of confusion.

Figure 2.2.1b. On this stair, the exposed aggregate of the concrete treads creates both a randomized figure-ground pattern which distorts depth perception, and a rough edge which confounds edge detection. Such a stair is particularly hazardous for the elderly or others with poor eyesight.

Figure 2.2.1c. On this stair the combination of (1) randomized patterns created by the travertine marble treads, (2) squared-off nosings which minimize highlights, and (3) uniform lighting which cancels out the modeling effects of contours and textures, make it almost impossible to detect the edges of the treads.

Figure 2.2.1d. On this stair, an evenly textured carpet permits the rounded nosings and the directional lighting to work together to highlight the edge contours.

2.2.2 Visibility of Irregularities in Riser/Tread Dimensions

IF: any riser or tread in a flight of stairs differs in height or effective depth from any other riser or tread in the same flight by more than 1/2 in. or...

IF: any riser or tread differs in height or effective depth from an adjacent riser or tread by more than 1/4 in. or...

IF: the height or effective depth of any single riser or tread (except winders) varies by more than 1/4 in. across the width of the stair...

THEN: refinish the edge of every tread in the flight with a clearly visible strip of color, or illuminate the flight so that the

Figure 2.2.1a

Figure 2.2.1b

Figure 2.2.1c

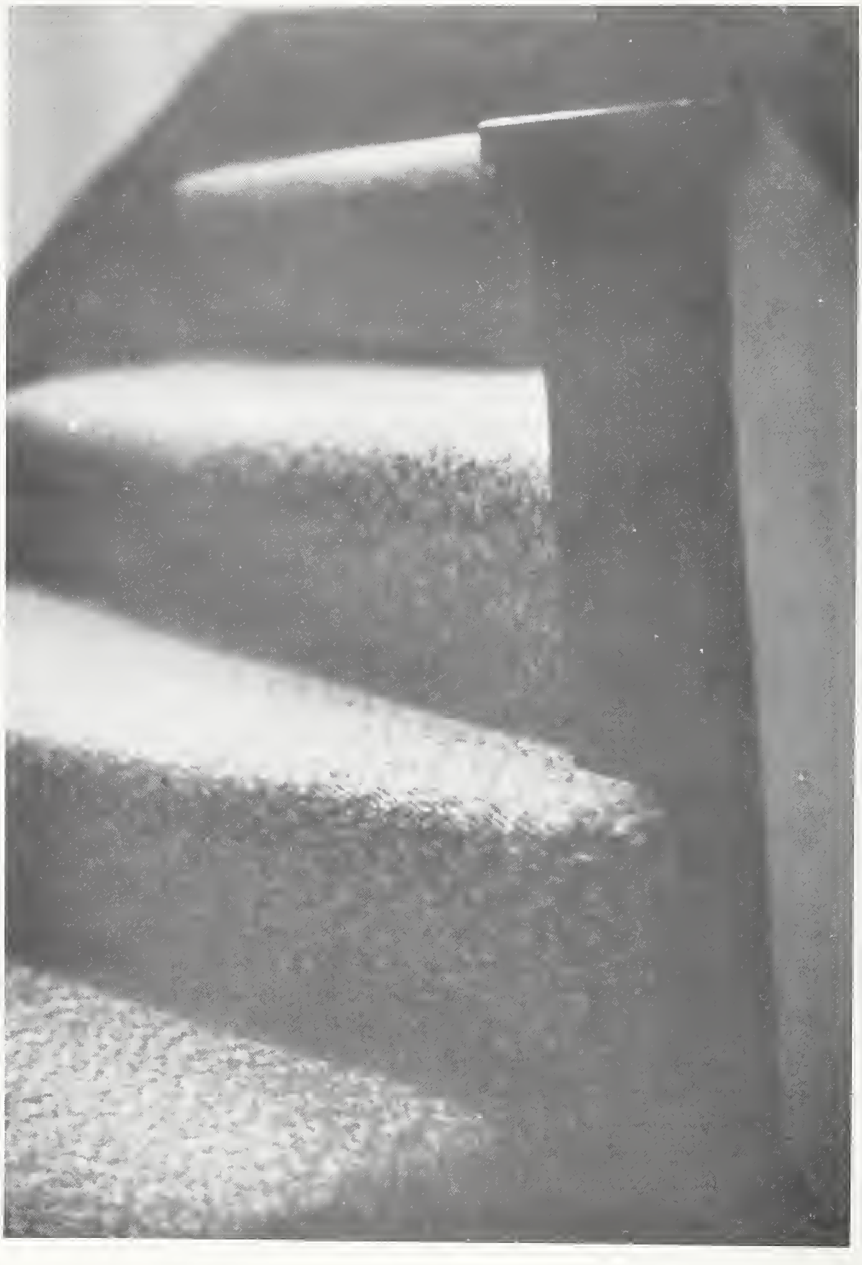


Figure 2.2.1d

highlighted nosings will produce a visual pattern of edges which accentuates the location of each irregularity.

Among the suggested ways to accomplish this are:

(a) mark the full edge of each tread with a single painted strip which extends not more than 1-1/2 in. into the tread from the nosing and which stands out against the remainder of the tread and surroundings in brightness value, and hue, or...

(b) provide surfaces, illumination, and nosings which interact to clearly accentuate the precise location of each tread edge.

COMMENTARY - It has been inferred from the NBS videotapes that when approaching a flight of stairs, the user first tends to look at the flight as a whole, then to look at the first several treads, and then to adjust his gait to the riser and tread dimensions. Since the user has only the appearance of the stairs to guide his behavior at this point, he tends to step higher to clear the first riser in ascent, or to cautiously lower his foot onto the first tread in descent.

As the user begins to ascend or descend the stair, he employs a new set of cues. If the tactile response to the first tread confirms the user's view of the tread, the user has some confirmation that the tread dimensions are as they appeared. If this confirmation occurs again on the second tread, the user is likely to believe that this stair has uniform dimensions. As the user's assurance about the uniformity of stair dimensions increases, he shortens his stride and reduces the allowance needed to clear each subsequent riser. The tactile information diminishes the need for the user to obtain information visually, leaving him free to look around at the environment surrounding the stair. Thus, the stair user may become susceptible to tripping on tread or nosing irregularities.

Evidence documenting the problem of riser/tread irregularity will be presented under Guidelines 2.6.1, 2.6.2, and 2.6.5. Additional evidence explicating the problem of tread-edge visibility was explored in the discussion of Guideline 2.2.1. While the empirical evidence suggests a strong relationship between the attention paid to the stairway and accident rates, there does not appear to be a strong relationship between the visibility of riser/tread irregularity and accident rates.

FIGURE

Figure 2.2.2. The second tread on this stair is more than one inch out of alignment with the other treads (note that the sunlight misses the second tread altogether). The third tread from the bottom is also slightly out of alignment (note a narrower band of sunlight than on adjacent treads).

Figure 2.2.2

2.2.3 Visibility of Irregularities in Carpet and Runner Materials

IF: the carpet on a carpeted stair has stretched or pulled loose and bulges out over the tread nosing...

THEN: tighten the carpet to its original position and secure it well.

COMMENTARY - As the user approaches and scrutinizes a flight of stairs from above, the edges formed where the uppermost surface on each tread folds over the nosing provides the primary visual cue to the dimensional characteristics of the flight. Since the user's success in adjusting his gait to meet the dimensional demands of the flight depends largely upon the accuracy of the visual information conveyed, it is imperative that the "apparent" edge seen by the user be the same as the "true" edge of each tread. If, for example, a carpet bulges out beyond the nosing of the stair tread beneath it, there is a distinct possibility that a user who adjusts his gait in accordance with the edge formed by the carpet will overstep the portion of the tread which has structural support and slip over the nosing. Insofar as the accurate and precise detection of the edge of each tread is the most critical factor in successfully descending a flight of stairs, every effort must be made to assure that the edge seen from above is a direct indication of the structural support available on each tread. If it is not, the unsuspecting user may be lured into placing the weight of his body beyond the point where it can be supported by the structure of the tread. The likelihood that this will lead to an accident is related to the confidence or assurance with which the user unknowingly oversteps the tread.

No data are available to demonstrate the notion that tread coverings which bulge over the structurally supported part of the tread can lead the user to misjudge the extent of each tread and incur an accident. However, some correlation between insecurely fastened tread coverings and stairway accidents has been reported. Velz and Hemphill (1953), for example, found that over 10% of the tread coverings in homes in which stair accidents had been reported were insecurely fastened. In 1961, Esmay found that insecure tread coverings were contributing factors in 6% of the stairway accdents studied. Several additional incidents of this type were reported in the NEISS in-depth survey analysis. In at least one of these cases, the cause of the accident was attributed to the visual effect of the carpet bulging over the nosing.

EXAMPLE

Accident A. The narrow, circular stair had no railing. When the victim's husband added the carpet to the stairs, he did not secure the carpet properly at the top of each riser and under the edge of each step. This made the actual edge of the tread above each riser difficult to locate. The victim slipped on the second step from the top, and slid down the next 3 steps. The victim sprained her right ankle. (NEISS)

2.2.4 Glare Reflected From the Stair Treads

IF: bright patches of glare reflected from the stair treads fall within the user's field of vision while looking at the stair from any point during ascent or descent...

THEN: reduce the reflectance of the stair tread surfaces from which light is reflected.

COMMENTARY - Hopkinson and Kay (1972) noted that the human eye cannot tolerate an excess of light. "While inadequate light leads to 'eye strain', discomfort, and distress, too much light leads to glare and dazzle, and consequently discomfort of a different kind. The designer has therefore to steer a middle course between lighting which is inadequate for its purpose, and lighting which taxes the adaptation mechanism beyond its comfortable limits. Under daylighting conditions, glare results from a very bright sky seen through a large window. Under artificial lighting conditions, glare arises through a direct view of excessively bright light sources inadequately screened." These investigators further noted that glare can be a function of contrast. If a bright light is seen in dark surroundings, it will cause more glare than if seen in light surroundings.

Discomfort due to glare, according to Hopkinson and Kay, may not be the only complaint. General efficiency and task performance were also found to be affected. Annoyance, frustration, and irritation were noted to be common among persons continuously explosed to glare-producing situations.

Silvers (1972) found that a glare source of 5 ft.-candles close to the central axis of vision provided a reduction in visibility equivalent to lowering the surrounding illumination level to 1/100 its original value.

Over (1966) studied visual factors in falls by elderly persons. He hypothesized that many falls may occur because unstable body position is induced by the false interpretation of visual information, which is not corrected by postural feedback. Although Over's hypothesis suggests inferences concerning a link between glare and stairway accidents, this relationship has not been empirically tested.

2.2.5 High-Contrast Shadows Parallel to Tread Edges

IF: a straight-edged, high-contrast shadow caused by a light source is cast upon a stair tread or landing such that it is parallel and adjacent to the top or the bottom of any risers in the flight, and...

IF: there are any color or brightness differences in the surfaces of the treads or landings in the vicinity of such shadows...

THEN: eliminate, or reduce the intensity of all such shadows in the vicinity of the flight of stairs.

Among the suggested ways to accomplish this are:

(a) block or reposition the offending light source while preserving the illumination on the stairs...

(b) reduce the intensity of the offending light source (unless this will reduce visibility on the stair), or...

(c) increase the amount of light available in the shadowed area by increasing the intensity of another light source, or...

(d) refinish the surfaces so that they have the same color and brightness values, or...

(e) extend or alter the edge which produces the shadow so that it is either no longer parallel to the tread edges or is no longer near the tread edges.

COMMENTARY - The detection of the edge of each tread is essential to the successful use of a stair. To the user, these edges will generally appear as linear discontinuities of color, brightness, or texture which run perpendicular to the path of travel. When a crisp shadow creates such a linear break on a stair tread or landing, there is an unacceptable likelihood that an unsuspecting user could misread the edge created by the shadow as the edge of a tread and, as a consequence, place his foot in a manner that could cause an accident. This is particularly critical on stairs where tread and landing materials already present light-dark contrasts to the user, or on stairs where the shadow edge might be mistaken for an additional step.

The data collected on the NBS videotapes indicated clearly that attention to visual cues is a critical factor in successful stairway use. Consequently, visual cues should be as accurate as possible to facilitate stair use. Miller and Esmay (1961) indicated that non-uniformities of steps and risers were found in about 75% of the stairs that they surveyed, and that about 60% of the stair accidents were attributable to missing a step. Clearly, extraneous or inaccurate visual information should be minimized so that the user can obtain an accurate perception of the actual stair characteristics.

2.3 HANDRAILS

Stairway handrails serve several important functions. First, they provide a surface along which the user can slide a hand, and thereby monitor his progress and stability during negotiation of the stair. Second, they provide a surface on which to pivot at corners or doglegs. Third, they provide extra support for an elderly or infirm user. Finally, handrails provide a grab bar necessary for support in the event of an accident on the stairway. Accordingly, the design and provision of adequate handrails are key tasks in any program of reducing stairway accidents.

2.3.1 Continuous Handrails

IF: an existing handrail is discontinuous at some point in the run of the stair, particularly at points where the stair makes a sharp 90° or 180° turn....

THEN: either replace the existing railing with a continuous railing, or fill in the gaps.

COMMENTARY - There are at least four critical uses of a handrail on a stair: (1) to slide a hand while monitoring one's progress and stability, (2) to use as a pivot at corners or doglegs, (3) to provide support for an elderly or infirm user, and (4) to grab onto for support in the event of an accident. The need to perform these functions prevails throughout the length of each flight and for all landings. Therefore, secure handrails should be available to the user at every point throughout his use of a stair. Moreover, the handrails should be continuous on the inside of 90° or 180° landings, and should be graspable at any point on the stair or landing. Interruptions in the continuity of handrails by newel posts, spindles, or brackets should be avoided.

McGuire (1971), during her analysis of data from the 1969 HUD survey containing some 4,000 inquires, found that 16% of all stair accidents could be attributed to missing handrails. This finding was underscored by Templer (1974), who noted that a substantial proportion of the stairway accident locations he investigated had no handrails.

Carson, et al., (1978), however, found no significant relationship between presence of handrails and accidents. They did find a relationship for the case of less serious incidents such as missteps, but this was in the opposite direction from that expected. Namely, on stairs with handrails, these incidents occurred 5 times as often as they did on stairs without handrails. As noted earlier in the Introduction, users may exercise greater caution when a handrail is absent. Furthermore, when handrails are absent the likelihood of a severe accident increases.

FIGURE

Figure 2.3.1. The need for continuous handrails (preferably 2) at all points along a flight of stairs is well illustrated by this accident victim (simulated) who has no other means to break her fall but to grab the handrail(s).

2.3.2 Handrails Comfortable to Grasp

IF: a handrail cannot be grasped by a typical user such that his thumb and index finger form a shape similar to the letter 'C', or...

Figure 2.3.1

IF: a handrail is positioned such that the user's fingers rub against a wall, mounting bracket, or other element when grasping the railing in the manner described above, or...

IF: a handrail is too slippery to permit a secure grip, or...

IF: a handrail becomes unbearably hot...

THEN: install or replace the railing in a manner that will permit a comfortable and secure grasp under all conditions.

COMMENTARY - During an accident, the primary purpose of the rail is to provide a point of anchorage. Consequently, the handrail should be available at all points throughout the flight, placed at a height within the user's reach, and structurally capable of supporting the user's weight under impact. The rail should have the following characteristics of dimension and texture:

a. grasp diameter - related to the size of the typical user's hand and to the degree of closure required to maintain a tight grip.

b. clearance from the wall - sufficient space between the rail and the wall to permit the user's fingers to wrap completely around the rail without touching a nearby surface.

c. abrasiveness of the wall - no surfaces in the immediate vicinity of the rail section should be so abrasive that if the user should touch the wall while grabbing the rail, he will not be able to withdraw his hand or be injured.

d. clearance at brackets - the points at which the supporting brackets attach to the rail should be positioned so that they will not interfere with the user's fingers, and cause him to lose his grip.

e. tactile quality of the rail - once the user has grasped the rail, he should be able to maintain a stable handhold. This depends upon: (i) the smoothness of the rail (absence of splinters or chipping paint); (ii) the slip-resistance of the rail (particularly if the user's hand is wet); and (iii) the thermal quality of the rail (particularly excessively hot rails).

From the videotape data, is is quite clear that the normal reaction to a misstep or a fall in descent is to grab the handrail. It is also clear from the videotapes that older stair users often hold onto the handrail for additional stability in both ascent and descent.

McGuire (1971) reported that 2% of all stair accidents were caused by handrails having sharp surfaces. Wheatley (1966) simply reported that "poor railings" caused a substantial proportion of all stair accidents.

In a study of 51 female stair users, Hall and Bennett (1956) found that a handrail diameter between 1-3/4 in. and 2 in. was preferred, and that

a diameter of 2 in. felt "most safe". Brill, et al., (1974) recommended that a handrail which could be grasped by 95% of the adult population would require a 3/4 in. diameter. Given the Hall and Bennett results on perceived safety it would appear that a 3/4 in. handrail might be too small. Therefore, a 1-3/4 in. to 2 in. dimension appears more appropriate. This is generally consistent with the recommendations by Teledyne-Brown (1972) for a maximum grip diameter of 2-5/8 in., by Grandjean (1973) for a maximum diameter of 6 cm to 10 cm (2.4 to 3.9 in.) and by Goldsmith (1967) for a circular section between 1-3/4 in. and 2 in. Goldsmith further recommends that handrails greater than 2 in. in diameter should have a special cross-section that permits easy gripping.

With regard to clearance between the handrail and adjacent walls, Sheldon (1960) suggested that the handrail should be of sufficiently small cross section and sufficiently far from the wall to permit the "grasp reflex" in an emergency. Teledyne-Brown (1972) recommended that this distance be a minimum of 2-1/2 in. Teledyne-Brown also recommended that all railings to be free of burrs, sharp edges, and sharp points.

2.3.3 Handrail - Guardrail on Open-Sided Stairs

IF: there are no handrails on one or both sides of an interior or exterior flight of stairs, or...

IF: the spacing of intermediate spindles or handrail supports is large enough to permit a person to easily climb under the rail itself, and...

IF: there is a vertical drop in excess of 1 ft. 0 in. beyond the edge of the stairway...

THEN: install a properly positioned guardrail, with an attached handrail, for the entire length of the flight.

<u>COMMENTARY</u> - If there is a sharp drop to one or both sides of a given flight, the user may become concerned that he will fall over the edge, and, consequently, become over-cautious. If the user should momentarily lose his balance on such a flight of stairs, it is possible that he might fall over the edge (or under the handrail) and suffer major injuries. Even an unanticipated drop of 1 ft. 0 in. or less can lead to severe injury and the possibility of long-term disability. For this reason, it is important that the possibility of falling over the edge of a flight of stairs be reduced through the use of an adequate guardrail. In this instance, a guardrail is intended to retard the passage of the whole body. This contrasts to a handrail which is intended to establish a firm and stable handhold. Where the drop is greater than 1 in. 0 in., both a guardrail and a handrail should be provided.

Incidents of this type were not recorded in either the NBS videotape data or the survey and inventory of stair use and quality (Carson, et al., 1978). Although several incidents were reported in the NEISS

in-depth follow up surveys, inadequate sampling made it difficult to assess the significance of these findings.

In a survey of guardrail design for the Occupational Safety and Health Administration (OSHA), Fattal, et al., (1976) suggested a guardrail with a top rail that is 42 in. above the walking surface. The width of intermediate rails and supports should reject the passage of objects 19 in. in diameter or greater. Since the OSHA study was done for industrial installations, it seems reasonable to reduce the height requirement for the top rail to the height of the handrail, and to reduce the rejection diameter to 5 in. for residential installations.

Teledyne-Brown (1972) recommended that stair rails should not permit passage of objects having a diameter greater than 5 in. Even this diameter may be too large where children are frequent users.

2.3.4 Dual Center Handrail for Wide, Heavily Used Stairs

IF: a given flight of stairs is wide enough for 3 or more users to ascend side-by-side....

THEN: provide intermediate sets of railings with dual handrails on each set so that every user is within an arm's length of a usable railing.

COMMENTARY - On wide high-volume or monumental stairs the user moving on the middle portion often has no handrail within his reach. Since it is the accident victim's first line of defense against a fall, he should have access to a graspable handrail. Therefore, sets of handrails which divide the width of the stair into segments wide enough to accommodate 3 or more than 3 channels of users simultaneously are called for. Furthermore, it is important that at least 2 handrails be provided on each segment of the stairs so that users on either side of the railing have access to a stabilizing element.

To date, no causal link between the provision of dual center handrails and accidents on heavily used stairs has been empirically established. For design purposes, however, the provision of such an amenity would appear to contribute to overall stair safety and ease of stair use.

2.3.5 Hand- or Guard-rail Terminations

IF: to exposed ends of any handrail or guardrail protrude directly into any portion of the user's clear path of travel during the approach to or use of a given flight of stairs....

THEN: extend or replace the end portion of the railing so that it terminates in a position that lies outside of any user's path of travel on or near the flight.

Among the preferred ways to accomplish this are:

(a) return the ends of wall-mounted railings to the wall, or...

(b) return the ends of free-standing railings toward the floor (possibly as a continuation of a supporting spindle or newel), or...

(c) connect the ends of discontinuous railings on the same flight or on adjacent flights.

COMMENTARY - Handrails which project up to 4 in. into either side of the user's path of travel are important components of a safe stair. Yet handrails which simply end abruptly near the end of the flight may be a hazard to a person approaching the flight. Under most circumstances the user is aware of the handrail and will select a path of movement that allows his body to clear the end of the railing. However, under crowded conditions, or momentary distractions, part of the body may pass close enough to the end of the railing to strike it. For most adults, the free-swinging hand and wrist, and the pelvic area are most vulnerable, whereas for young children the shoulders and face are at the handrail height. Given the extreme vulnerability of these areas, the exposed ends of railings should be designed to minimize the likelihood of injuries.

Although there does not appear to be any statistical relationship between handrail projection or protrusion and accident rate, the provisions suggested in this guideline will probably reduce the seriousness and frequency of stairway accidents.

2.3.6 Handrails on Stairs Frequently Used by the Elderly and Handicapped

IF: a given flight of stairs is frequently used by elderly persons...

IF: a given flight of stairs is frequently used by persons who have any permanent sensory or physical disability, or ...

IF: a given flight of stairs is frequently used by persons who are under the influence of drugs or medication...

THEN: provide handrails on both sides of the flight.

COMMENTARY - Persons who have either (a) diminished capabilities for performing the sensory and motor functions necessary to negotiate a stair successfully, or (b) some uncertainty about their ability to perform such functions, may require additional means of support as they use a flight of stairs. The following problems are typical:

(1) secondary support in descent - when descending a flight of stairs, a fully sighted person can usually see where to place his feet. However, because a person with diminished visual capability may not be able to judge the extent of the tread

below, he may not be sure that his foot will have a firm footing until he has actually made contact. Unfortunately, when descending a stair, people generally have to release the support provided by their trailing leg (the one on the higher step) before their leading leg makes contact with the tread below. Therefore older people and other persons with visual impairments encounter an interval of time during each step when they can neither support their weight on the tread above nor be assured that their weight will be supported on the tread below. Furthermore, the duration of this interval increases as the speed of movement decreases (which occurs as a person becomes less sure of his next foothold). As a result of this precarious situation, persons with difficulties judging the extent of the treads below may have to hold onto the handrail, almost as if it were a "third leg". By holding onto the handrail in this manner, the person can acquire the support necessary. Accordingly, such supplementary support should be available whenever a visually impaired user might require it.

(2) grab-bar in ascent - persons with diminished strength may require a handrail to pull themselves up from one tread to the next. Whereas most people can elevate themselves from one tread to the next with their leg muscles, those who do not, may have to use their arms to pull themselves up from step to step. However, this requires a handrail or some other object to pull against at every point where a physically impaired user might require it.

(3) fulcrum in ascent or descent - in addition to the perception and stamina problems covered in (1) and (2) above, some stair users who have problems in flexing certain joints may not be able to perform movements typically required for stair use. As a consequence, they may have to improvise unique patterns of stair movement. Since such persons lack the capability to perform the required movements on their own, they may use portions of the stair as prosthetic devices to supplement their own capabilities. In such cases, the user may actually use the handrail as an extention of his own skeletal system. Since the specific disabilities associated with this kind of stair movement are so varied, handrails are needed on both sides of each flight.

When these 3 problems are considered along with the occasional need to break a fall, it is clear that secure, graspable handrails on both sides of each flight should be provided for elderly or handicapped stair users.

Although a number of injuries involving older persons were reported in the NEISS in-depth surveys, the most dramatic evidence was found on the NBS videotapes. Numerous incidents involving older persons were recorded, including: people reaching for non-existent handrails in ascent; people pulling themselves up from step to step; and people

relying heavily on the handrail for support. While the sampling procedures used did not permit statistical treatment of these classes of behavior, preliminary analysis at NBS showed that older persons tended to move more slowly on stairs than younger adults. In addition, Templer, et al. (1978) noted that there were more incidents than expected for persons who used the handrail to balance or pull themselves up than for persons who either did not use the handrail or who only used it for guidance. This finding is strongly suggestive of the vulnerability of the user groups who require supplementary support.

Sheldon (1960) reported that 28 of 63 stair accidents among the elderly might have been prevented if adequate handrails and illumination had been provided. He recommended handrails detached from the wall on both sides of stairs used by the elderly. This agrees with Templer (1974) who found that, despite a tendency to use the right hand side of the flight, Americans will frequently violate the norm if it shortens their overall path of travel. Data from the residential stair use survey and stair quality inventory in Milwaukee (Carson, et al., 1978) shows that while accidents on stairs are not related to the absence or presence of handrails, accidents tend to be more serious on flights that do not have them. While this cannot be directly related to the special problems of the elderly and handicapped, data from the same study show that the elderly tended to use stairs less frequently than younger adults, but when they did, they were more likely to use the handrail. Taken as a whole these various sources of data tend to support the notion that elderly stair users have needs for handrails that are quite different and somewhat more urgent than the remainder of the adult population.

EXAMPLES

Accident A. The 78-year old victim turned, waved to a friend, lost his footing, fell over backwards down the stairs onto a concrete walk, and fractured his ribs. There was no handrail.

Accident B. The 77-year old victim fell down the steps leading to the rear door of her house and fractured her left hip. There was no handrail.

Accident C. The 78-year old victim fell over backwards down the stairs onto the concrete walk. He received a cut on his head and three broken ribs. The concrete steps had sides made of flat stone. There was no handrail.

Accident D. As the 70-year old victim reached the fourth step from the bottom, he became dizzy, fell backwards, and hit his head against what he thought was the floor. He dislocated his right shoulder. There was no handrail.

2.3.7 Support at the Ends of Handrails

IF: there are older persons who use the stair, and...

IF: a handrail is already installed...

THEN: check to make certain that supports are secure at all end points along the rail - particularly, avoid long runs of the rail beyond the last support at the top and bottom of the stair.

COMMENTARY - Older people tend to use handrails for support and will often tend to exert fairly heavy loads on the rail near the top or bottom of a stair. In order to avoid railing failures, additional brackets should be installed.

Sheldon (1960) studied 171 accidental falls by elderly persons. Some 63 of these falls occurred in connection with stair use. Sheldon noted that about 1/3 of the stair-related falls might have been prevented by the adequate provision of handrails. He also suggested that extra support be provided at the top and bottom ends of stairway handrails.

Templer (1974) noted that age was not a significant contributor to stairway accidents. This was corroborated by his later finding (Templer, et al., 1978) that 68% of all persons observed in the 5-44 age group had incidents, while 65% of all persons observed in the over-45 age group had incidents. In fact, fewer persons over 65 (44%) had stairway incidents. This in contrast with the NEISS data which suggest that although older people have fewer accidents, these accidents are generally more severe.

Templer, et al. (1978), also noted that relatively few of the people he observed utilized handrails for physical support (1%), or for pulling themselves up (3.5%). People generally used handrails for balance (9.4%), guidance (23.3%), or not at all (62.9%).

2.3.8 Intermediate Handrail for Children up to 6 Years Old

IF: a given flight of stairs is frequently used by children up to the age of 6 years ...

THEN: provide an intermediate handrail on at least one side of the flight which is mounted 24" above the surface of the nosing edge of each tread.

COMMENTARY - Young children are simply too small to utilize a handrail which is 34 in. to 36 in. above each tread. In order to use a handrail that is positioned for adults, a small child may have to adopt an abnormal and hazardous posture. Thus, a handrail that is positioned so that it can be grasped just above a child's waist level is desirable for children. In addition, younger children (1-3), who have less experience on stairs, tend to take two steps on each tread, and may require the handrail for added support. Because the child's hand is smaller, it may require a handrail of smaller diameter. Finally, such handrails should be continuous throughout the flight, and have sufficient clearance to permit uninterrupted use.

The NEISS data suggest that children under the age of 4 years have twice as many stair accidents as expected based on their distribution in the U.S. population (data are for 1972). From the NEISS in-depth surveys and the NBS videotape data, it is clear that young children have a disproportionate number of missteps, falls, and accidents. It is also clear (from viewing the videotapes) that handrails mounted for adults provide no support or recourse for accident or misstep victims in this age group. Since very few of the stairs recorded or observed had intermediate handrails, it was not possible to determine the effectiveness of handrails placed at a lower height.

2.3.9 Openings in Handrail Supports (For Children)

IF: a given flight of stairs is accessible to children less than 3 years old, and...

IF: the vertical or horizontal openings permit a sphere greater than 4 in. to pass through...

THEN: reduce the size of the openings so that a sphere greater than 3-1/2 in. in diameter cannot pass.

COMMENTARY: Young children, even if they cannot walk, can be attracted to stairs as exciting places to play and test their own capabilities. Among the more attractive parts of the stair are the handrail and supporting balusters and spindles. Whether the child is playing with the spindles themselves, or is merely playing on the stair, there is a possibility that he might lose his balance and fall between the handrail supports, onto a surface below. For young children, the waist and chest may slip through an opening, leaving the head lodged between the spindles. Serious head and neck injuries are possible in these cases.

Although no incidents of this type were reported in the NEISS in-depth survey data or on the NBS videotapes, the tapes did reveal several young children playing near or with handrail supports. As a result of research on stair accidents, Teledyne-Brown (1972) recommended a handrail opening that would reject the passage of a sphere 5 in. or more in diameter. However, from anthropometric data on children, it appears that the 50th percentile 2 year old has a hip depth of 4 in. and a head width of 5-1/4 in. These numbers indicate that the depth at the hip is a critical dimension, since it is smaller. For a 1 year old child, this figure is 3-1/2 in. Since the 1 year old (while too young to actually walk on stairs) is likely to be the most vulnerable to these kinds of incidents while crawling on stairs and pulling himself up on the handrail, the latter figure is proposed as the appropriate design criteria.

2.4 SURROUNDING ENVIRONMENT: PHYSICAL CHARACTERISTICS

Improving the physical characteristics of the environment surrounding the stairs is as critical to stair safety as maintaining the structural integrity and quality of the stairs themselves. The surrounding environment can best be defined as including the walls and ceiling of the

stairway, windows, light fixtures, skylights, doors, and entrances in the stair area. In general, the surrounding environment should be designed to facilitate normal use of the stair, and to minimize potential distractions. In addition, it should be free from elements which might injure a user further once he has fallen.

The surrounding environment should provide adequate headroom without projections into the stair area. The stair should not force the user to duck his head, twist awkwardly, or make evasive movements, while negotiating the stair. There should also be a clear path of travel through the stairway, and no doors should swing into the stair area. In addition, the quality and quantity of illumination should be adequate and reasonably uniform over the stair. Furthermore, the user should be able to see obstructions or other users in the stairway at all times, so that he is not suddenly surprised or distracted.

Further injury during a fall can be minimized by removing all projections and rough surfaces in the stair area. Finally, access to the stair should be restricted for very young children.

2.4.1 Clear Path of Travel for Flights and Landings

IF: there are doors which swing within one tread depth of the top or bottom riser in a flight of stairs, and/or...

IF: the flight is obstructed by a door at the top or bottom landing...

THEN: reposition or modify the doorway such that someone approaching the flight can become aware of other persons on the flight, prior to encountering the stair itself or hitting the perscns with the door.

Among the suggested ways to accomplish this are:

(a) reverse the swing of each offending door (if possible under the prevailing fire exit requirements), or...

(b) remove the doors (contingent upon exit, heating, and security requirements), or...

(c) install a fire-rated glass panel in the door, (where required by fire codes), so that a person approaching the door can see someone else using the flight. Where fire-rated glazing is not required by code, use safety glazing.

COMMENTARY - In some cases, stair accidents result when a person nearing the top of a flight is struck by a door or another person, and is consequently pushed backwards down the stairs. Frequently, the person who strikes the victim is unaware that the other person is on the stairs until after the accident has begun. To eliminate such an incident, remove any visual obstructions. Where possible, either reverse the

swing of the door away from the stair, remove the door, or provide a glass panel in the door so that obstructions or persons in the stairwell are visible.

The key problem here is to assure that a stair user will not be struck by a door or another person at the top or bottom of a flight. In new construction, this problem can be solved if adequate landings are provided at the top and bottom. So long as there is adequate landing space, the user within the stairwell will at least have a level place to stand to avoid being struck. In existing situations, because it is seldom feasible to add landings to stairwells, reversing the door to swing away from the flight, or removing the door altogether, reduces the likelihood that someone will push another person off the landing or risers. In addition, removing the door or placing a glass panel in it will enable a person approaching the flight to see other people on the stairway, and to react accordingly.

Several incidents of this type were reported in the NEISS in-depth studies. None were recorded on the NBS videotapes or on the Milwaukee survey and inventory (Carson, et al., 1978). But since a disproportionate number of stairway accidents are typically expected in cases where doors swing toward stairs, it has become common to recommend that the top landing be at least 30 in. deep (Teledyne-Brown, 1972). Grandjean (1973) recommends that landings behind doors should be at least 50 cm (19.7 in.) deep, and that there should be a sign warning of stairs located behind doors. Teledyne-Brown (1972) also suggested that such doors should swing away from the stair.

EXAMPLES:

Accident A. The mother opened a swinging door to let the victim into the house. The victim, standing just outside, was bumped by the door, fell down the five cement steps, and incurred a concussion. The door opened to the side of the safety railing.

Accident B. The victim, a 4-year old male, was standing at the top of a set of 3 steps just outside the screened porch. Suddenly, the porch door blew open and knocked the child down the steps. He broke both front teeth.

2.4.2 Clear Headroom Throughout the Flight

IF: any user of a given flight of stairs frequently strikes the ceiling, lighting fixture, or another overhead member during normal ascent or descent, or...

IF: any household member or frequent guest can touch any portion of the ceiling, lighting fixture, or another overhead member with his head while standing on his toes at any point in the flight...

THEN: either remove the offending hazard or provide an unambiguous cue to its presence and location.

Among the suggested ways to accomplish this are:

(a) remove or raise the hazardous surface or projection over the flight (making certain not to interfere with essential structural members), or...

(b) provide a clearly visible contrasting cue (which should not be so compelling that it distracts the user's attention from the treads and handrail) to the hazard's precise location, or...

(c) cushion the offending edge(s) of projections to minimize the consequences of unavoidable contact, or...

(d) place signs warning of the hazard which are clearly visible from the approaches to the landings.

COMMENTARY - It is evident that sufficient headroom is needed at all points along a flight of stairs to permit users to pass without contact. In fact, unless the low headroom is obvious, most users will traverse the stairs assuming that all overhanging fixtures or projections are high enough to permit clear passage. This last point is critical to those situations where there appears to be sufficient headroom, but in fact there is not. In such cases, the user will have no reason to take evasive action and may actually be more vulnerable to hitting his head.

No incidents involving low headroom were recorded on the NBS videotapes. This is because all the flights studied were free of obvious hazards. Several incidents were reported in the NEISS in-depth studies, but these could not be treated statistically due to biased sampling procedures. Carson, et al., (1978) determined that 16% of all residential (interior) stair flights had low headroom. Furthermore, there was a tendency for more accidents to occur on flights with low headroom than on flights with adequate headroom. McGuire (1971) noted that 2% of the stair accidents reported in a HUD survey could be attributed to insufficient vertical clearance.

There is some disagreement on the required vertical clearance for safe passage on a flight of stairs. Teledyne-Brown (1972) suggested a minimum of 7 ft. 4 in. Grandjean (1973) recommended 200 cm. (approximately 6 ft. 6-1/2 in.) measured either vertically from the nosing or perpendicular to the slope of the flight.

EXAMPLES

Accident A. The 16-year old youth received a concussion when, because of low ceiling clearance, he hit his head on the ceiling above the stair and knocked himself unconscious.

Accident B. The 28-year old respondent was able to enumerate 10 separate accidents on her home stairways within the past year. She reported that the basic problem was low head clearance (of 60 to 62 in.) on both stairs. Most accidents followed the same pattern: she or her husband

hurried down the stairs, forgot about the low ceiling, and hit their heads on the overhang. None of these accidents required medical attention. (Carson, et al., 1978)

2.4.3 Physical Conditions Which Cause the User to Divert Attention From the Stair

IF: there are points of low headroom or restricted width caused by a projecting door frame, light fixture, bracket, ceiling, etc. within a stairway, or...

IF: there are high velocity or foul air currents blowing across a stair at the level of a user's face -- such as those created by exhaust fans, air conditioners, or...

IF: there is dripping moisture caused by a refrigeration unit, a clogged downspout, or a missing gutter over a stairway, or...

IF: gutters or natural drainage channel water onto tread or landing surfaces, or...

IF: depressions in walking surfaces allow water to puddle or back-up, or...

IF: it is possible to see a mirror, or a highly polished surface that acts as a mirror, or...

IF: it is possible to see a television screen while ascending or descending a stair...

THEN: eliminate or relocate the offending physical conditions.

COMMENTARY - Being distracted by water or foul air while using a stair may be as dangerous as being struck by an actual physical projection within the stairway. It is obvious that physical projections ought to be eliminated. What is less obvious, however, is that other distracting conditions also ought to be avoided, because they can draw the user's attention away from the stair.

Water running across stairs and landings can decrease the slip-resistance of the surface. In addition, water can decrease the detectability of the surface characteristics of a stair, and, in some cases, even obscure the edges of the treads.

The potential for being distracted by images in a mirror or a television is, in part, a variation of the "orientation edge" problem. (See Section 1.2.4). The primary issue is whether the stair or something else in the surroundings is a more compelling focus for the user's visual attention. In addition, mirrors located on stairs or landings may present distorted information in which stairways and landings appear much wider than they actually are. Furthermore, the image of a single handrail in a mirror may occasionally be mistaken for a real handrail.

Esmay (1961) found that 8% of the stair accidents he studied could be attributed to distractions which caused users to look away from the stair itself. Johnson, et al., (1975) attributed 58% of the accidents they studied to the users' failure to look down at the approach to the stair. Although no evidence was found to link the rate of stair accidents with the presence of run-off water on stairs or landings, it is evident that any materials which impair either the slip-resistance, stability, or detectability of a surface ought to be avoided. There is no statistical evidence that links mirrors or televisions with stair accidents, but there is some documentation (the NBS videotape analysis) which indicates that extraneous visual information can contribute to a misstep or a fall.

2.4.4 Projections in User's Clear Path of Travel

IF: there are coat hooks, picture hangers, nails, light fixtures, or shelves protruding into the stairway at any point up to 75 in. above the tread surface, or...

IF: brackets or hinges remain where railings or doors have been removed...

THEN: remove them.

COMMENTARY - Sharp projections into a stairway can cause both accidents and injuries. Hooks or light fixtures are usually conspicuous enough to be avoided. There is also a likelihood that clothing or some item being carried will catch on the protruding element and throw the user off balance. No amount of precaution or familiarity can assure that such incidents will not take place. Furthermore, the user must be in complete control of his own movements. The most critical threats occur when an accident sequence has already begun, since the user is not in control of his fall. Accordingly, it is essential to remove from stairways all protrusions that could increase the severity of injury upon impact.

The residential survey conducted by Carson et al., (1978) indicated that a number of stairways had projections into the user's path of travel. Velz and Hemphill (1953) and Esmay (1961) also indicated that projections could result in an accident or increase the severity of an accident in progress.

EXAMPLE

Accident A. The respondent's 2-year old child fell off a winder near the bottom of a flight of stairs and cut his head on a hinge that had previously supported a gate. (Carson, et al.)

FIGURE

Figure 2.4.4. In this 2-story townhouse, the master bedroom projects out over the open stairway, creating a sharp edge and corner just a few inches above the handrail. The owner's niece dislocated her shoulder while sliding her hand along the railing.

2.4.5 Splinters, Protrusions, Sharp Edges, and Abrasive Contact Surfaces

IF: the surfaces of any railing, spindle, tread, nosing, or other component of a stairway exposes any user to splinters, protrusions, or sharp edges under normal usage, or...

IF: any nails or screws protrude above the surface or component in which they are embedded, or...

IF: any treads, walls, or other surfaces within the stairway expose rough or abrasive textures to user...

THEN: refinish, refasten, or replace the offending material(s) in a manner that reduces the possibility of puncturing, cutting, tearing, or scraping upon sudden or sustained bodily contact.

COMMENTARY - Extremely coarse textures on stairway surfaces can increase the severity of a fall by causing flesh wounds upon contact. Fragments of materials that break off from these surfaces can also become embedded in the skin. Similarly, a nail or screw that extends from the wall or from a metal nosing strip, can pose a serious hazard to the user who suddenly tries to regain his balance, or who shuffles his bare feet across the treads. Aside from catching on clothing, these surface irregularities offer little likelihood of causing an accident by themselves. Yet, by the very manner in which they break the surface of the skin upon impact, they can turn an otherwise minor incident into a painful injury.

The survey of residential stairs (Carson, et al., 1978) indicated that a number of the stairs were in rather poor condition, with rough surfaces and projections. Although there does not appear to be any statistical evidence which links increased accident rates with surface protrusions, it is evident that these could distract the user's visual or tactile attention.

EXAMPLE

Accident A. The 36-year old housewife was returning up the tilted and uneven wooden stair when she lost her balance midway up the flight. When she extended her right hand to steady herself, it landed on a protruding nail which severely lacerated the tip of the fourth finger. (NEISS)

Figure 2.4.4

2.4.6 Glass Areas In or Near Flights of Stairs and Landings

IF: any portion of an exterior window within a given stairway is less than 75 in. above an adjacent tread surface, or...

IF: any portion of an exterior window or glass door on a landing at the bottom of a flight of stairs is within 36 in. above the bottom riser of that flight <u>and</u> less than 75 in. above the landing surface...

THEN: protect such glass areas from contact or breakage by a person who might fall or impact upon them in an uncontrolled manner.

Among the suggested ways to accomplish this are:

(a) use safety glazing materials in all windows, doors, or partitions exposed to persons falling on stairs, or...

(b) place at least one (more if the exterior glass area is high above ground level) guardrail across the entire glass area, mounted approximately 36 in. (98 cm.) above the floor or adjacent tread surface.

<u>COMMENTARY</u> - Once an accident victim has lost control of his movement on a flight of stairs, it is difficult to anticipate how he will regain control or how he will impact on surrounding surfaces. However, if one of the surrounding surfaces is glass, and if the glass breaks, the possibility of serious injuries from shattered glass is greatly increased. Consequently, it is important to reduce the likelihood of (1) impacting the glass surface in the first place and (2) shattering the glass if it is struck by the victim's body.

Ideally, both a guardrail and safety glazing should be used to diminish the likelihood and the severity of glass-related injuries resulting from stair accidents.

Determining which glass areas are most likely to be struck may be difficult. However, assuming that the victim can reach in any direction to try to break a fall, then all glass areas that lie below the standing height of a 99th percentile male (75 in.) should be protected. To accommodate most uncontrolled falls on the lower landing, all glazing within 75 in. should be protected.

<u>EXAMPLES</u>

<u>Accident A</u>. As the 13-year old boy descended the stair, he turned to say something to his friend and tripped when he was about 2 steps from the bottom. Because he could not regain his balance, he plunged headlong into the lower glass portion of the storm door. He lacerated himself behind the ear, lodged a piece of glass in one of the main arteries in his arm, and cut his thumb. The ornamental grating on the outside of the door prevented him from going completely through. (NEISS)

Accident B. The 18-year old male was leaving his girlfriend's apartment when he missed a step and fell into the outside door, putting his arm through the glass in the upper half of the door. Glass shards caused deep puncture wounds on his left arm. (NEISS)

Accident C. As the 19-year old male was returning in the house, he either slipped or tripped on the steps and fell through the lower glass section of the aluminum storm door at the top of the steps. A sharp shard of curved glass fatally punctured the right side of the victim's throat near the clavicle. (NEISS)

2.4.7 Stair Flights Which Are Not Readily Visible

IF: there are stairs within the dwelling unit in which the upper landing (or top tread) is obscured by a door which is normally in a closed position, or...

IF: there are flights of stairs within the dwelling unit which descend from areas that are normally used for sleeping...

THEN: provide a luminous cue within the stairwell which is clearly visible from a point on the user's approach to the stair, prior to his having reached the top nosing, and which clearly indicates the drop in floor level.

Among the suggested ways to accomplish this are:

(a) provide a night light on the side wall of the stairway which is in line with the user's approach to the stair, and which is at least one riser-depth below the level of the upper landing, or...

(b) arrange to have a discernable amount of illumination reach the upper landing and treads of the obscured flight(s) at all times of the day or night.

COMMENTARY - Two common types of residential stair accidents occur: (a) when people proceed through a door, only to find themselves falling down an unexpected flight of stairs; or (b) when someone awakens in the middle of the night, inadvertently turns the wrong way, and falls down the flight of stairs. Both types of accidents are common among people who are unaccustomed to the layout of an unfamiliar home. However, each can also occur among people who are quite accustomed to their own homes but who, due to drowsiness, stress, drugs or fatigue, misjudge their own immediate surroundings.

To counteract this problem some type of warning signal must be provided that can penetrate the user's inattentiveness and elicit the most effective reaction.

Under these circumstances, a luminous signal would be more likely to evoke the most effective response than a less conspicuous cue such as

high color contrast between the treads or handrails and the walls of the stairwell. The cue should fall within the approaching user's most likely line of sight. Finally, by placing the cue below the level of the upper landing, a sense of depth can be conveyed which will alert the oncoming user to the possibility of falling. Since the issue here is to alert the unsuspecting user to impending danger, an important characteristic of this luminous cue is its conspicuousness, as opposed to the amount of illumination cast upon the stair treads. This cue is intended solely to stop the user's forward progress, not to improve his ability to negotiate the stair.

Although annecdotal accounts abound, there are few data which link stair accidents to the obscuring effects of doors or darkness. Velz and Hemphill (1953) indicate that doors which swing toward the top step of a stair flight are dangerous, but they have no accident data to support their assertion. However, they do report that 39% of the interior residential stairways which they surveyed had doors near the top of the flight. These doors averaged 18 in. from the top nosing. In addition, 20% of these doors opened toward the stairs. In 1961, Miller and Esmay reported that 8% of the accident victims in their survey had not intended to use the stairs at all. These investigators suggested, though they did not document it, that most unintentional uses resulted when a stair flight was mistaken for an entry to another room, and where a door swung out over the flight without a top landing. McGuire (1971) reported that 3% of the stair accidents reported in a HUD survey were attributed to doors swinging over the stairway.

Neither the NBS videotapes, nor the residential survey included any incidents of this type. While the in-depth analysis of the NEISS data showed a number of accidents occurring in the homes of friends or relatives, these data are insufficient to establish the effects of darkness or doors on the possible confusion or disorientation of accident victims.

In all of these reports, only Miller and Esmay (1961) make any recommendations to alleviate this condition. Their recommendation is to install night lights on stairs that might be confused with entries to other rooms.

<u>EXAMPLE</u>

<u>Accident A</u>. The victim was spending the night at her sister's house. In the early morning she got up to go to the bathroom. The bathroom door was directly opposite the door to the basement. The victim opened the door to the basement, thinking it was the door to the bathroom, and stepped out into the open space, thinking she was stepping onto the bathroom floor. Loosing her balance, she fell down the basement stairs, breaking her upper arm.

2.4.8 Illumination of Stairs

IF: a light bulb which contributes to the illumination of any portion of a stair or stairway burns out...

THEN: replace or add an electric light of similar wattage and color rendition immediately... If a change in the quality or quantity of the light is desired, warn stair users that stair conditions have been altered (however slightly).

COMMENTARY - The quality of illumination in the stairway provides most of the cues about current stair conditions for the user. Any change in the amount, color or direction of the illumination may lead the frequent stair user to pay attention only to the change and, hence, to respond as though the physical conditions have changed. In addition, the user who is unfamiliar with the stair urgently needs adequate illumination to detect prevailing stair conditions. Consequently, not only should stairways be lit by natural or artificial illumination, but care should be taken to make sure that there are no abrupt changes in this illumination from day-to-day.

The NBS videotape analysis indicated that the user's initial awareness of the presence of a stair is primarily visual, as shown by the downward direction of the head and eyes. Although a user may rely more upon tactile-kinesthetic cues for subsequent steps, the initial sensory impression of the stair is a visual one. Consequently any change in the amount or quality of light within the stairway could seriously impair visual detection of stair characteristics and surrounding cues. Templer (1974) in fact found that poor illumination was a contributing factor in a number of stair accidents.

EXAMPLES

Accident A. The victim was descending the stairs when she tripped on the second flight and fell the last 3 or 4 steps. Although the normal lighting in the stairway was inadequate, provided only by a single yellow bulb over the landing, this bulb had burned out. When the respondent found the victim, she was lying unconscious on the floor with her head on the first step. She received a slight concussion.

Accident B. Although there was a light socket in the ceiling of the hallway of the victim's apartment, it did not contain a light bulb. Some light was provided by a bulb on the next lower floor which shone on the lower treads of the stair. The victim, who was holding the trash with her right hand and the bannister with her left hand, stepped down from the (upper) landing. She missed the first step, fell 15 steps to the bottom of the flight, and fractured a rib.

2.4.9 Control Switches on the Top and Bottom Landings

IF: the lighting on a stairway is controlled by the user, and 3-way switches at the top and bottom landings of the stairway are not provided...

THEN: 3-way switches and wiring should be installed at all landings and should be accessible at least 1 stride before the first riser is encountered.

COMMENTARY - Except for those public or semi-public stairs where the illumination is not under the user's direct control or those short (1 to 3 riser) flights of private stairs where all necessary lighting is provided by spillage from adjacent rooms or spaces, the availability of artificial light on a stair should be subject only to the user's discretion. The user must be in a position to alter the amount of artificial light available during his use of the stair. This means that on and off switches should be provided at every point of entry to or exit from the stairway. No stair user should have to traverse a stair in the dark because the only switch is at the other end, and no user should feel obligated to leave the lights off because there is no switch at the other end.

The importance of visual cues for successful stair negotiation, suggested by the data collected on the NBS videotapes, indicates that provision must be made to ensure adequate light levels for all stair uses. Three-way switches and wiring are one way of providing the user with immediate control over lighting in the stairway.

2.4.10 Stairs Accessible to Children Under Four

IF: children 4-years old or younger can gain access to a stair which is located within or adjacent to their dwelling unit...

THEN: provide and use a reliable, stable means for controlling such access...

COMMENTARY - Data taken from the NEISS in-depth studies indicate that stair accidents occur with greater frequency among children who are 4 years old or younger than any other age group. Many of these injuries occur when children wander onto stairs and are unable to negotiate them successfully. Simply limiting access to stairs, by means of a secure door or gate, can prevent falls which occur when a child unknowingly enters a stairway. Care should be taken, however, to minimize potential danger to children who climb on an unstable gate.

The NEISS data, as well as the residential survey data, contained numerous examples of injuries to children who wandered into a stairway, and fell. Because very young children are unable to negotiate stairs successfully, limiting their access to stairways would appear to be an effective means of controlling accidents.

EXAMPLES

Accident A. The victim, a 17-month old boy, wandered off and his mother's attention was gained by hearing his crying on the second floor landing. The child fell down the flight of 14 steps, and received a concussion. (NEISS)

Accident B. The victim, a 9-month old baby, was allowed to crawl around the floor unattended. The door to the basement had been left open. The mother heard the victim crying and found him at the bottom of the stairs between the main floor and the basement. He had a bruise above his right eye. (NEISS)

Accident C. The victim's sister left the door to the basement stairs slightly ajar. The 18-month old victim was able to walk his baby walker to the door and pull open the door. He pulled the front edge of the walker over the top step and tumbled down the stairs. He suffered contusions and abrasions on his head. (NEISS)

2.5 SURROUNDING ENVIRONMENT: APPEARANCE

In addition to physical conditions in the stair surroundings which can injure the user, the appearance of the surrounding environment can distract the user's attention causing him to misstep or fall. The data recorded on the NBS videotapes underscored the importance of visual attention in successful stair negotiation. Any characteristic of the stair or stair surrounding which distracts a user from paying full attention to the essential details of the stair is potentially dangerous.

Thus, the conspicuousness of the tread against the surroundings should be enhanced. Orientation edges and changes should be minimized. Furthermore, views through the stairs should be screened or minimized. Contrast between the stair and the surroundings should be maximized so that the stair, not the surroundings, is conspicuous. Glare from bright light sources should be minimized, particularly for elderly or visually handicapped users.

2.5.1 Color and Lighting Contrast to Accentuate Treads and Handrails

IF: the stair treads and handrails are not the most conspicuous features in the user's visual field while approaching or using a stair, or...

IF: there are compelling points of visual interest that compete for the stair user's attention while approaching or using a given flight...

THEN: refinish the treads, handrails, or surrounding walls, and relight the stairway in a manner that will emphasize the treads and handrails and deemphasize everything else the stair user can see.

Among the suggested ways to accomplish this are:

(a) refinish the treads and handrails in lighter, warmer colors and refinish the walls and ceilings of the stairway in somewhat darker, cooler colors and/or...

(b) increase the lighting intensity on the stairway slightly while decreasing the lighting intensity in surrounding areas or...

(c) provide lighting which falls more directly onto the stair treads and less directly on surrounding walls or other competing sources of visual attention.

COMMENTARY - The stair treads and handrails should be the most conspicuous objects in the user's visual field. As the stairs are approached, the visible slope of the handrail and the series of tread nosings are the most reliable cues which indicate to the user that there are stairs in his pathway. In addition, the zigzag pattern of risers, treads, and nosings against a sidewall or baseboard may be a good cue.

Once the user is aware of the stair, he must know the position and condition of the tread surfaces and the handrail, in order to use the stair successfully. In addition, the user should know about any related surrounding features which might precipitate an accident.

Anything that makes the treads and handrails stand out against their background, will consequently, contribute to the successful use of a flight of stairs. Other information about components of the stairway and the surrounding environment is unnecessary for the proper use of the stair, and may even distract the user's attention away from the stair itself.

Whether or not a person actually looks at the stair during the critical first steps appears to be the most powerful discriminator between successful and unsuccessful uses. The analyses of the NBS videotape data showed that more than half of the stair users who had missteps did not look at the stairs as they approached them (Johnson, et al., 1975). On the other hand, all successful users did look. If looking at the stair is indeed a crucial behavioral requirement for successful stair use, then it is necessary to ensure that the critical parts of the stair will attract the user's attention, and that the less critical surroundings do not.

2.5.2 Abrupt Changes in View From a Stair

IF: there are particular points on a flight of stairs from which a user can suddenly see into a room, hallway, or other space located off to the side of the stair which had previously been blocked from view, and particularly...

IF: such an abrupt expansion of the visual surround occurs at the top or bottom of the flight...

THEN: diminish the impact of the localized distraction in a manner that will either block or reduce the conspicuousness of features or events that become visible off to the side of the stair, and increase the attention-getting qualities of the stair itself.

Among the suggested ways to accomplish this are:

(a) modify the relative lighting patterns so that the level of illumination on the stair treads and handrails exceeds the levels found in surrounding areas and...

(b) extend or reduce the opening so that its edge is farther from the extreme ends of the flight.

COMMENTARY - As people move from an already familiar area to one which has just come into view, they tend to glance around the corner (or edge) to survey the newly revealed surroundings, particularly if these are more open than the enclosed stair area. The researchers at NBS labeled such corners as "orientation edges" and the tendency to look around them as the "orientation activity". This often subconscious process of attending to suddenly changed surroundings may be quite compelling -- particularly in unfamiliar places where a person is uncertain about potential hazards.

As suggested by the model of stair use (see Section 1.2.4), the following inferences may be drawn about the role of orientation edges in stair use. Orienting to places and situations can create a dangerous conflict if it occurs in conjunction with the beginning of a flight of stairs. An important factor in successful stair use involves looking down at the stair treads from at least one stride away from the first riser until the completion of the first step on the stair. If an "orientation edge" is located at the beginning of a stair flight, the user may find himself attending to the view beyond that edge at precisely the time when he should be looking down at the walking surface. This can lead to a misstep or an accident for the user who has not obtained enough information about the stair. Although orienting distractions are more critical near the top or bottom of a flight, they can also disrupt the subconscious monitoring of gait in the middle of the flight, and this can trigger an accident. Orienting distractions can occur not only for vertical edges but for horizontal edges as well. The ceiling line of a first-floor living area or hallway on a residential stair can distract a descending person, for example.

The abruptness with which new scenes are introduced and the conspicuousness of these scenes are important factors which contribute to the likelihood of distraction by an orientation edge. Abruptness is, in turn, dependent upon the user's rate of movement and distance from the edge itself. Conspicuousness depends on the apparent contrast between the color range and illumination on the stair and in the visible portions of the surroundings. Since many of these factors (except the rate of movement) are controllable through design modification, it appears that orientation distractions introduced by "orientation edges" on stairways are correctable. The need to correct this problem seems to be greatest at the top of a stair flight where the most serious accidents frequently originate.

Esmay (1961) found that distractions were contributing factors in 8 of the 101 stairway falls he investigated. Several accidents reported in

the NEISS in-depth studies were reported to have happened "for no apparent reason" on the fourth through seventh step from the bottom of the flight. In at least 6 of these incidents, combined data on the victim's height, the height of the risers, and photographs of the stairs suggest that the victim's eye level would have just passed below the horizontal orientation edge created by the first floor ceiling as he moved onto the step indicated as the beginning of the accident. A number of incidents reported on videotape also occurred just as the victim's head passed an orientation edge at relatively close range.

The NBS incident analysis of these videotapes showed that the second most powerful discriminator between high- and low-risk stairs, for the samples studied, was the number of orientation changes from one step to the next. Templer, et al. (1978), found that the greater the number of changes, the greater the number of missteps or accidents. According to Templer, et al., components of the orientation edge which increase the likelihood of incidents are: stimulating views available on one side of the stair only, stimulating views directly ahead of the user, and a greater number of changes in the user's visual surroundings from step to step in descent.

The data do not demonstrate that "orientation edges" actually cause accidents. For the stair studied, it was never clear where the accidents began and it was impossible to determine to just which stimuli the users were actually attending. However, the data suggest the notion of the orientation edge as an area in which future research may prove fruitful.

EXAMPLES

Accident A. The victim, a 3-year old girl, was coming down the stairs into the living room of her house. She became extremely excited when she saw a friend, a little boy of the same age, enter the living room through the front door. For no apparent reason she lost her balance and fell down the last 7 steps, fracturing her left elbow. (The point at which she first noticed her friend, and from which she fell, is the point at which her eye level would have passed below the ceiling of the living room, or an "orientation edge".) (NEISS)

Accident B. A young woman carrying a purse on her arm descended a 4-riser flight to a landing and then fell onto the top step of a 22-riser flight in a sitting position, apparently incurring no injury. As she approached the landing, her view of the lower level (of the shopping center) was obstructed by a low wall. The wall ended at the top of the lower flight, precisely where she had fallen (NBS videotape).

FIGURE

Figure 2.5.2a. As users approach this stair from above, they must first descend into an enclosure which completely obscures their view of the scene below. At the top of the flight, the enclosure ends, creating a

Figure 2.5.2a

view of the floor below. This scene is exposed to descending users at precisely the point where their attention should be directed toward the stair itself.

Figure 2.5.2b. In this case, a horizontal orientation edge is created by the intersection of the ceiling of the floor below and a low wall around a balcony above. As the user's eye level passes this edge, a large activity area is revealed to the extreme right.

2.5.3 Impact of Views Through Open Risers

IF: a flight of stairs has open risers and...

IF: it is possible to see human activity, interesting scenes, or objects of curiosity through the openings between the treads while ascending the stair...

THEN: provide modifications in material, color, or illumination patterns which diminish the likelihood of a user's attention being directed toward events visible through the stairs, and thus neglecting conditions on the stair themselves.

Among the suggested ways to accomplish this are:

(a) alter the patterns of illumination on the stair and in the area exposed through the risers so that the levels of light falling on the stair treads are noticeably greater than the levels in the area seen through the stairs and...

(b) refinish or repaint the stair treads and/or the visible features of the space seen through the risers so as to accentuate the visibility of the stair treads and diminish the visibility of the area seen through the stairs, or...

(c) fill in the open riser with an opaque or translucent material that is rigid and firmly affixed to the treads above and below, and which completely blocks the user's view of scenes through the stair.

COMMENTARY - The potential for being distracted by a view through an open riser is a variation of the "orientation edge" problem. Here again, the primary issue is whether the stair itself or something in the surrounding is a more compelling focus for the user's visual attention. The only additional hazard associated with views through open risers is related to the interference or flicker introduced by the stair treads which appear to move across the foreground while the user ascends the stairs. The resulting discontinuous view through the open risers may induce the user to neglect the stair itself, because he must concentrate on overcoming the repeated disruption created by each passing tread.

If the user stops to scrutinize the scene before resuming his ascent, he could block traffic and be a potential hazard on heavily traveled stairs.

Figure 2.5.2b

Furthermore, once stopped, the stair climber will have to repeat the process of getting onto the stair in a manner much like his original transition from level walking to stair walking. Since the user's vulnerability to accidents seems greatest while making such a transition, all such conditions should be avoided.

According to conventional wisdom, open risers are hazardous because people could slip and catch their legs in the openings, and because young children might get caught in - or might even fall through - an opening. The literature review, the NEISS in-depth studies, the videotapes of 1-riser stairs, and the residential survey, indicated that no accidents of these types were reported.

However, if one accepts the idea that orientation distractions can trigger stair accidents, then the possibility of being distracted by what one sees through open risers is at least plausible. Although there appears to be only anecdotal data which relate accident rates to open risers, extrapolation from the data on the rate of visual distractions in stair use suggests that open risers could contribute to stair accidents.

FIGURE

Figure 2.5.3. The scene revealed through the open risers of this public stairway can be a much more compelling focus of attention than any part of the stair itself.

2.5.4 Hotspots of Direct, Reflected, or Diffused Light Within the Stair User's Normal Field of Vision

IF: light bulbs, lighting fixtures, direct sun, or bright patches of reflected light fall within the user's field of vision from any point during ascent or descent...

THEN: either (a) block the source of glare with translucent or opaque shades or screens, (b) reduce the reflectance of any surfaces which reflect bright lights or (c) move the offending bulb or fixture beyond the range of the user's functional visual field.

COMMENTARY - The total amount of light on the treads and handrails is one of the critical factors in the user's ability to detect prevailing stairway conditions. However, an adequate quantity of light does not ensure that the quality of illumination is particularly good on a given flight of stairs. If the angles of incidence and of reflectance combine with highly reflective surfaces to produce glare when the user looks at the treads, increases in light level could actually diminish his ability to acquire useful information. Finally, when the source of illumination falls within the user's visual field while looking at the stair, there is a distinct possibility that the intense brightness in one portion of the visual field may actually reduce the user's ability to acquire useful information from the remainder of the visual surroundings.

Figure 2.5.3

On many residential flights of stairs, the fixture which illuminates the stairway is clearly visible when the user is looking toward the stairs in descent. This condition may not only reduce a person's ability to discern details, but could also produce an afterimage which makes it difficult to process any visual information for several seconds afterward. Glare from overhead light sources, and the resulting afterimage, becomes even more critical for the elderly and visually handicapped (Pastalan, et al., 1973; Weale, 1963). During ascent, similar glare problems can arise from lights over an upper landing or from decorative lighting beneath stair treads.

Windows in stairways can also cause glare. A sunny or an overcast sky can produce glare directly, or a dirty window or sheer curtain can scatter direct sunlight into the stairway. These reduce the effective visibility of a stair. Regardless of the amount of light available under such circumstances, the user's ability to process the visual information required for successful stair negotiation can be significantly reduced by direct or reflected glare from this light.

When Velz and Hemphill (1953) surveyed a number of homes, they found that over 60% of all intermediate landings on stairways had windows. Glare can be a particular problem with windows because of the high levels of illumination during daylight hours (Hopkinson, 1972). In addition, for the elderly recovery from changes in lighting levels within the visual field occurs much more slowly (Wolf, 1960; Weale, 1963). As a result, maintaining an adequate ratio of illumination between the surround and target is critical. Wolf (1960) suggested that the illumination in the surround must be increased proportionately to any increase in the target illumination. Consequently, windows and bare light bulbs should be placed so that they are not directly within the user's view.

2.5.5 Changes in Light Level Between Stairs and Their Surroundings

IF: a stair is located within 2 or 3 normal strides of an exterior doorway, or...

IF: the rooms or spaces that one must pass thorugh immediately before entering or immediately after exiting a stair are substantially more (or less) brightly lit than the stair itself...

THEN: the contrast between the levels of illumination on the stair and its surrounding should be lessened: by (1) changing the level of illumination on the stairs or surrounding; or by (2) providing supplementary illumination between the stairs and adjacent areas that is of intermediate intensity.

COMMENTARY - The human eye is very sensitive to the total amount of light. As a person moves from one place to another, his eyes continually adapt to the changing light levels. If the change in light levels is too sudden or too great (as when coming indoors from bright sunlight), his eyes are unable to adapt fast enough to permit clear vision. In such cases, a person would be unable to discriminate details on stairways,

and may even be unable to detect the presence of the stair itself. Consequently, it becomes necessary to either locate stairs as far away as possible from zones of abrupt changes in lighting levels or to provide transitional lighting to compensate for the momentary incapacities of the eye.

Because the human eye does not adapt immediately to large changes in lighting levels, extreme variations in light levels within the approach to, exit from, and passage through a stair should be avoided. The problem is accentuated for the older person who experiences much greater light scatter within the eye as well as decreased ability to adapt to rapid changes in illumination (Weale, 1963).

Hence, gradual changes in illumination between the stairs and their immediate surroundings should be provided. Otherwise, the surroundings should be designed to allow the user time to adapt to the general illumination level before he is required to negotiate stairs.

2.5.6 Accentuation of Single Steps, 2-Riser Stairs, and Encroachments

IF: there is a single step or a 2-riser stair within a landing, or in a hallway, sidewalk, plaza, patio, foyer, or room or...

IF: there are 1 or 2 steps leading to or from an entryway, sunken living room, raised platform, or porch, or...

IF: the treads of any stair encroach onto an adjacent room, hallway, or sidewalk...

THEN: provide patterns of illumination, color, or other cues which emphasize the location of the step, stair, or encroachment to draw the user's attention to it.

Among the suggested ways to accomplish this are:

(a) provide handrails on both sides of the stair or encroachment which clearly stand out against their backgrounds, and...

(b) increase the intensity of the lighting on the step, stair, or encroachment slightly while decreasing the lighting intensity slightly in surrounding areas, and/or...

(c) refinish the stair treads and surrounding surfaces in a manner that will accentuate the visibility of the treads and the top landing for 2-riser stairs, encroachments or single steps, or...

(d) provide a change in ceiling level which corresponds to the change in elevation of the step, stair, or encroachment, or...

(e) place warning signs which clearly indicate the presence and location of the unexpected stair.

COMMENTARY - Single steps, 2-riser stairs, and encroachments may not be noticed by the person approaching them, especially from above. Sloping handrails, a major cue used to identify a stair, may not be used on a short flight of stairs, or may be spaced too far apart on monumental stairs, or may not be visible in an encroachment. The zig-zag edge of treads, risers, and nosings may also be too remote to be a clear signal for the "stair".

Moreover, the small overall change in floor level may be particularly difficult to see in a 1 or 2-riser stair situation, or in the visible portion of an encroachment. When approaching from below, people may trip and fall forward over unexpected risers. When approaching from above, they may step out into mid-air. Any changes in the stair materials or lighting which draws the user's attention to these situations should reduce the frequency of stair accidents.

The use of handrails to signal the presence and location of 1 and 2-riser stairs or encroachments is suggested for several reasons. For example, it is likely that an obvious stair component such as a handrail which is placed high above the floor, will attract more attention than a cue built only into the walking surface. In addition, since the apparent distance of a fall from a 1 or 2-riser stair is limited, appropriate precautions are less likely to be exercised. In these situations, therefore, handrails may be needed to break the fall as well as to indicate the presence of a stair.

The NEISS in-depth studies suggested that one of the most prevalent stair accident scenarios involves tripping over or stepping past 1 and 2-riser stairs and encroachments. Many of the incidents reported occurred in a location other than the victim's home.

The critical incident analysis of videotape data gathered in public settings (Templer, et al., 1978) also suggested a significant tendency for more missteps and accidents per tread on shorter flights than on longer ones. This trend was not found in the residential survey (Carson, et al., 1978), although 1-riser stairs did show, as logic might suggest, the highest rate of accidents per tread. The data seem to suggest that the likelihood of accidents on 1 and 2-riser stairs and encroachments may be related to unfamiliarity, a factor which may account for the higher rate in public settings and the lower rate in one's own home.

Tha analyses of NBS videotape data also suggest a high susceptibility to missteps and accidents while making the transition from level walking to stair walking. These analyses also suggested that a number of persons failed to notice a short stair, and that they jumped directly to the landing without using the intermediate step(s).

2.6 DIMENSIONAL INTEGRITY AND STRUCTURAL QUALITY

The dimensional integrity and structural quality of a stairway is assessed in terms of the ability of a stair to maintain its strength and stability under loading, and in addition, to provide a continuous and

regular walking surface. Stair components must combine to support the loads applied at any time by the maximum number of expected users. Moreover, a stairway must be constructed and maintained in such a manner as to provide a uniform and continuous rise in elevation throughout its length. Maintenance procedures and the quality of repair, as well as initial installation practices, will affect structural integrity and quality.

Whether constructing new stairs or retrofitting existing ones, the assemblies and components should withstand the combined effects of loads applied by the users, including impact loads imparted by falling persons. Such forces should be withstood without permanent structural deformation, and without deflections or displacements which are excessive.

The dimensional relationships among the critical components of a stair should enable the user to easily execute all exploratory, ascending, descending, or corrective movements necessary for successful passage. Finally, the configuration of a stairway must permit a continuously moving user to maintain equilibrium while using any part of the assembly, without contortions or disruptions to accommodate other persons moving in either direction.

2.6.1 Excessively Steep Stairs That Are Frequently Used

IF: the riser height exceeds the effective tread depth on a given flight of stairs, or...

IF: the riser height exceeds 9 in., or...

IF: the effective tread depth is less than 9 in....

THEN: consider replacing or rebuilding the entire flight.

<u>COMMENTARY</u> - Carson, et al., (1978) found no statistically significant data suggesting a relationship between the steepness of stairways and accident rates. This finding was corroborated by Templer (1974). The steepness of the stair may trigger increased vigilance, and thus reduce the likelihood of an accident.

Carson, et al., (1978) however, did note that stairway steepness depends on the particular combination of riser height and tread depth, of which there are many. For inside stairways in their site sample, 48% of the stairways were of 1 of the 4 combinations of 7-1/2 or 8 in. risers, and 10 or 10-1/4 in. treads. Outside stairways in the site sample had riser heights averaging 6.9 in., with a mean tread depth of 12.3 in. Some 33% of all stairways in their site sample had either 7 or 7-1/2 in. risers and either 11-1/2 or 12 in. treads. Note that these riser/tread dimensions exceed those recommended in Section 2.1.1, and are believed to constitute a serious stair hazard.

2.6.2 Excessively Irregular Stairs

IF: any riser or tread in a flight of stairs differs in height or effective depth from any other riser or tread in the same flight by more than 1 in. or...

IF: the height or effective depth of any single riser or tread (except winders) varies by more than 1 in. across the width of the stair...

THEN: consider redesigning or replacing the entire flight.

THEN: for variations which are less than 1 in., see 2.2.1.

COMMENTARY - According to Velz and Hemphill (1953), "non-uniformity of step dimensions may affect the balance and timing of persons using stairways to cause them to misstep, overbalance, stumble, or fall with the subsequent possibility of serious injury. Minute variations in step dimensions may be caused by faulty step construction methods, materials, maintenance, and also to settling or shifting of the entire structure due to similar defects. Uniformity of step dimensions is not only important in a single stair flight but should be observed on all stairways in a dwelling structure." In the residential stair survey, Carson, et al., (1978) found that about 15% of all indoor and outdoor stairs were reported by residents to have had noticeable irregularities (1 in. or greater). Actual measurements taken at stair sites by the investigators defined 46% of the sample stairways as having such irregularities.

Velz and Hemphill (1953) reported that 4 out of 13 stairways on which accidents had been reported were characterized by, among other factors, non-uniformity of step dimensions. Esmay (1961), in his study of 101 home stairway accidents, found that non-uniformity of steps accounted for a large percentage of the accidents. Note that although 2.2.1 recommends increasing the visiblity of all irregularities, the irregularities given in 2.6.2 appears to be excessive enough to warrant stronger measure.

2.6.3 Broken Treads, Handrails, Nosings, and Spindles; Loose Nails, Screws, Bolts, Brackets, or Other Fasteners

IF: stair treads or nosings are chipped, splintered, broken, excessively worn, etc., or...

IF: handrails or spindles are broken, or...

IF: impact or user loads cause noticeable movement in treads, risers, handrails, or connections, or...

IF: handrails are loose...

THEN: replace or repair them with materials which are similar in strength, slip-resistance, and/or appearance to the original, and/or... tighten, brace and otherwise correct the structural deficiency or prohibit use of the stair.

COMMENTARY - Velz and Hemphill (1953) noted that about 30% of all tread surfaces on stairways surveyed were not considered to be in good condition. Carson, et al., (1978) solicited comments concerning repair requirements from their occupant sample. Many of these comments pointed to obvious needs such as the repair of broken concrete, the replacement or repair of broken treads, or even the construction of entire replacement stairways.

Nevertheless, no statistical evidence was found to demonstrate a relationship between stairway condition or repair requirements, and accident rates, perhaps because people may use greater care if the stair is in poor condition. It seems reasonable to assume, however, that a serious accident potential may exist on such stairs.

EXAMPLES

Accident A. The victim was at the top of a flight of concrete steps serving a wooden porch which was in poor condition. The boards were heavily worn and partially rotted where the porch adjoined the steps. There was no railing on the stairs and the rail along the porch was weak. She caught the heel of her shoe on one plank and fell sideways and landed on her back. (NEISS)

Accident B. At the top of the stairs, the victim lost his balance and fell down the 12 stairs. He had been holding onto the handrail; but since it was loose and not firmly attached to the wall, it provided no support when he lost his balance. The injury was contusions. (NEISS)

Accident C. The victim, a 60-year old woman, was using the handrail while descending a stairway in a department store. The free-play in the handrail caused her to lose her balance and fall down 6 steps. She received an abrasion on her hand. (NEISS)

2.6.4 Dilapidated Wood or Metal-Framed Stairways

IF: the typical walking surfaces or supporting members of a wood or metal framed stair are rotted, broken, racked, or otherwise incapable of providing needed support...

THEN: replace the entire flight and support structure, or... ban the stair from use.

COMMENTARY - It is essential that stair treads be capable of supporting the weight of stairway users throughout the travel distance, and obviously, stairways which cannot meet this basic criterion require immediate replacement. Dilapidated stairways still capable of supporting loads should be banned from use. Where this is not possible, signs warning of

the hazard should be posted in a conspicuous manner. Although no evidence was found showing a statistical relationship between stairway condition and accident rate, a serious accident potential should, however, be assumed to exist whenever stairs are in dilapidated condition.

2.6.5 Stairs Which Have Treads Severely Canted to the Right or Left

IF: the settlement of 1 side of a given flight of stairs, or of the structure to which it is attached, produces a constant slope to the right or left in excess of 1/2 in. per linear ft. (a 4.2% slope)...

THEN: replace the entire flight and supporting structure.

COMMENTARY - The severe canting of steps to one side or the other may result from faulty construction methods, materials, and maintenance, or from the settling or shifting of the entire structure. Step non-uniformity caused by canting may affect the balance and timing of persons using the stairway, and may therefore cause them to misstep. Although no evidence was found demonstrating a statistical relationship between canting and accident rates, a potentially hazardous situation should be assumed to exist.

EXAMPLE

Accident A. The respondent's husband slipped on the outside wood steps as he was leaving for work. The 5 steps on the accident flight had settled, producing many irregularities. Between the first and second steps, there was a 2-1/2 in. difference in riser height. Furthermore, there was as much as a 1 in. difference in riser height from the left to the right side for a single step (Carson, et al.).

2.7 SIGNS AND SYMBOLS

Signs and symbols should be used to facilitate the use of stairs. Because stairs allow people to move from one elevation to another, people should be warned in advance of the location and destination of a stair, particularly in a public building with several stairs.

Movement within a building is not aided when a stair leads to a detour, a dead-end, a wrong destination, or an unessential change in elevation. In most cases this may be independent of the stair itself, but related instead to a series of pathways connected to the stair. Since stairs can be hazardous, consume human energy, and contribute to fatigue, the introduction of a stair where none is required or desired is a serious design error.

Finally, stairways should be clearly differentiated from other portions of a building; the destinations of stairs and alternative pathways (elevators, escalators, hallways, etc.) should be clearly marked; and stairs should not be installed where they are not needed for vertical travel.

2.7.1 Locating Alternate Means of Vertical Movement

IF: in residential buildings, which use stairs to effect vertical movement...

IF: there are means of vertical movement other than stairs...

THEN: install signs which clearly indicate the locations and destinations of the alternate means.

Among the suggested ways to accomplish this are:

(a) provide clearly visible and legible signs or unambiguous symbols indicating the location of both stairs and alternate means of transportation

(b) enhance the conspicuity of the alternate means of vertical movement through lighting and color contrast

(c) be sure that the signage and markings are clearly visible from the approach to the stairs.

<u>COMMENTARY</u> - In 1976, the Consumer Product Safety Commission rated stairs as one of the two most hazardous consumer products in the home. The Commission attributes at least 4,000 deaths per year to accidents on stairs (see Table 1 in the Introduction). In addition, stairs demand a level of expenditure of human energy at three times the rate required by level walking (Templer, 1974). Particularly for older person, the handicapped, those carrying objects, or virtually anyone on a long flight of stairs, the energy expenditure on stairs could lead to fatigue or even an attack or seizure. As a result, any unnecessary use of stairs, especially when there is no change in elevation, should be avoided. Thus, when alternate means of vertical movement, such as escalators, ramps, or elevators, are available, they should be clearly and unambiguously indicated prior to the last choice point.

The data collected by CPSC on the dangers inherent in stair use indicate that either stairs should be made considerably safer or that stairs should be avoided whenever possible. Unless the user can be made aware of alternative means of vertical movement, through signs and symbols, he cannot elect to avoid stairs. Fruin (1971) notes that signs should confirm the basic building configuration and that both should provide direction, orientation, and purpose to the user.

2.7.2 Orientation of the User to Specific Stair Destinations

IF: stairs in residential buildings are accessible to the general public, visitors, or building personnel...

THEN: provide a clear indication of the specific stair destination at points prior to entry to, or exit from, the stair.

Among the suggested ways to accomplish this are:

(a) use clearly visible and legible signs or symbols to indicate specific destinations (such as the garage, laundry, rental office, etc.). Such signs should be visible before the user begins his ascent or descent of the stairs, and at each level of egress from the stair.

(b) place a sign or symbol indicating floor level and any specific destination at each entry/exit point in a multi-level stair. Do not place the sign/symbol in such a manner that it will divert the user's attention from the stair.

COMMENTARY - Because stairs are hazardous, people should not be forced to use them in a search for particular destinations, such as rental offices, telephones, laundries, etc., in a residential building, unless the stairs actually lead to those destinations. In public or semi-public places, the locations of all commonly sought facilities and destinations of all stairways should be made apparent to the user before entry to the stair. In multi-level buildings, the floor number should be indicated at all points of entry/exit to avoid unnecessary stair use. Unnecessary stair use is time- and energy-consuming for the user. Furthermore, sudden stops or changes in direction on a stairway can be disruptive or hazardous to others on a stair.

2.7.3 Entries to Locked Fire Stairs

IF: doors to residential stairs are locked on the stairway side (for reasons of security, or for other reasons)...

THEN: place a warning sign outside of each point of entry to the stairwell which indicates the points at which there are exits from the stair.

Among the suggested ways to accomplish this are:

(a) place a visible and legible sign or symbol which indicates the exit location on both sides of the entry door at all points of entry above the exit location.

(b) place a sign inside the stairwell which indicates that exit is available only on a particular level.

COMMENTARY - People attempting to use fire stairs to travel within a multi-storied residential building often find themselves locked inside the stairwell and forced to descend to the lowest level to exit. While such stairways must be unlocked from connecting building floors to meet fire exit requirements, these stairways are commonly locked from the stairway side so that unwanted intruders will be unable to gain access to the upper floors. In hotels, hospitals, or high-rise apartment buildings, persons who may only be trying to get ice or to bypass a slow or crowded elevator can find themselves trapped into making an unintentional

trip to the sub-basement just to get out of the stairwell. Since stairs are a very hazardous consumer product (see 2.7.1), every effort should be made to ensure that people are not victimized by locked fire stairs.

2.7.4 Essential Facilities at Each Level for the Elderly or Handicapped

IF: the elderly and/or handicapped are required to use stairs to gain access to an essential facility such as a telephone or a bathroom...

THEN: install needed facilities on each level where these users will spend substantial time.

COMMENTARY - The energy expenditure for stair climbing noted by Templer (1974) is a particular problem for the elderly and handicapped. Furthermore, data collected from the NEISS survey and by Carson, et al., (1978) indicate that the severity of stair accidents is higher for the elderly than for other segments of the population. As a result, because of the particular vulnerability of the aged, their use of stairs should be minimized whenever possible.

The increased danger inherent in stair use for the elderly (Sheldon, 1960) suggests strongly that they should avoid stairs whenever possible. As noted by Pastalan, Mautz, and Merill (1973), Agate (1966) and Weale (1963) the elderly suffer from deficits in most sensory capabilities. Because these deficits include a wide range of visual handicaps such as cataracts, glaucoma, yellowing of the lens, increased adaptation time, and general decreased sensitivity, stairs, which depend upon visual cues for successful negotiation, can be a particular problem for the aged or visually handicapped. In addition, surveys of actual conditions on stairs by Carson, et al., (1978) and Miller and Esmay (1961) indicated that light levels were inadequate and poor on as many as half the stairways surveyed. As a result, Agate (1966) recommended that the elderly live on one floor as much as possible. Duplication of essential facilities in a multi-level dwelling would appear to accomplish the same purpose.

2.7.5 Cues on Walls and Ceilings to Mark the Beginning and Ending of Stairs

IF: a given flight of stairs is ever used while carrying bulky objects such as small children, luggage, or...

IF: a given flight is frequently used by large numbers of people simultaneously...

THEN: provide clearly identifiable cues on adjacent walls, ceilings, or elsewhere in the upper portion of the users' visual field which unambiguously indicate the location, alignment, and direction of the beginning and end of each flight.

Among the suggested ways to accomplish this are:

(a) provide easily noticed handrails which extend at least 1 ft. beyond the nosing at the top landing, and at least 1 tread-depth plus 1 ft. beyond the nosing of the bottom tread (except in encroachment situations). These should reveal a distinct break from the slope of the stair to the horizontal, and/or...

(b) align the break-points of the ceiling with the nosing at the top landing, and with a point beyond the nosing of the bottom tread.

COMMENTARY - One way to think about a stair is as a break in the flat plane of a walking surface, which is interrupted by a set of treads which either protrudes above a lower plane or receeds below an upper plane. When the user looks down at the floor or landing, he should see this change in plane and be prepared to negotiate the stairs. However, if the view of the walking surface is obstructed by other people or by carried objects, the user is much less likely to notice this change in the floor plane. Alternative cues such as the slope of the handrail, the slant of a moulding strip or paint edge that conforms to the slope of the stair, the slant of the ceiling, or a combination of the above can signal the presence and direction of the stair.

When all of the cues available to the user give the same message, there is a much greater likelihood of that message getting through. When the cues convey different messages, however, there is a great chance that the most critical cue... such as the one signalling the presence and direction of the stair... will be missed by the unsuspecting user who is being guided by the others. If a ceiling line, painted edge, or wall stripe continues horizontally beyond the point where a stair descends, a conflict between cues will exist. While most people will probably notice the stair, the wall and ceiling treatments clearly deny the fact that the floor level changes, and may lead some users to have an accident.

Esmay (1961) and Miller and Esmay (1961) reported that "arms full" was cited by victims as a common cause of residential stairway accidents. Using the stair while carrying large objects was given as the primary or secondary cause in 25 of the 101 stair accidents investigated.

Likewise, the incident analysis of the NBS videotape data (Templer, et al., 1978) indicated that persons carrying objects tended to have more missteps regardless of how the object was carried. This finding, however, was not statistically significant. There also appeared to be some tendency for women carrying children to exhibit much more precautionary foot movements throughout the stair. Furthermore, this tendency was more pronounced for the side on which the child was carried (the side on which the visual obstruction was the greatest).

No direct evidence is currently available to identify the precise role that special markings on walls or ceilings might play in preventing such accidents. Yet, a key factor involved in stair incidents appears to be the visual obstruction of the walking surface by carried objects or by

nearby persons. The potential magnitude of this problem is underscored by the finding from the NBS residential survey (Carson, et al., 1978) that stairs were used when doing the family laundry and taking out the trash in 96% and 94% of the residences surveyed, respectively.

EXAMPLES

Accident A. The victim was going down a narrow stairway with his arms full of garbage, which he was carrying out to the back of the house. The stairs were poorly lighted and made 90° bend about 2/3 of the way down. At the bend where the tread width varied from 3 in. to 12 in., the victim fell and fractured his left ankle. He said he could not see the stairs because his arms were full. (NEISS)

Accident B. The respondent had just returned from the grocery store and was carrying 2 large grocery bags to her upstairs apartment. As she reached the step next to the landing, she missed the step, and fell on her left side. She sustained a simple fracture and contusions of the left elbow and left leg. (NEISS)

FIGURE

Figure 2.7.5. On this stairway, the slope of the handrail and the paint pattern on the wall provide reliable cues for the direction, slope, and location of the first riser. Such cues in the upper part of the visual field are important whenever other users or objects obscure the user's view of the tread surfaces themselves.

2.7.6 Non-Visual Cues for Visually Handicapped Users at Entrances to and Exits From Stairs

IF: a stair is frequented by the elderly, handicapped, or visually impaired user...

THEN: provide non-visual cues at the top and bottom landings.

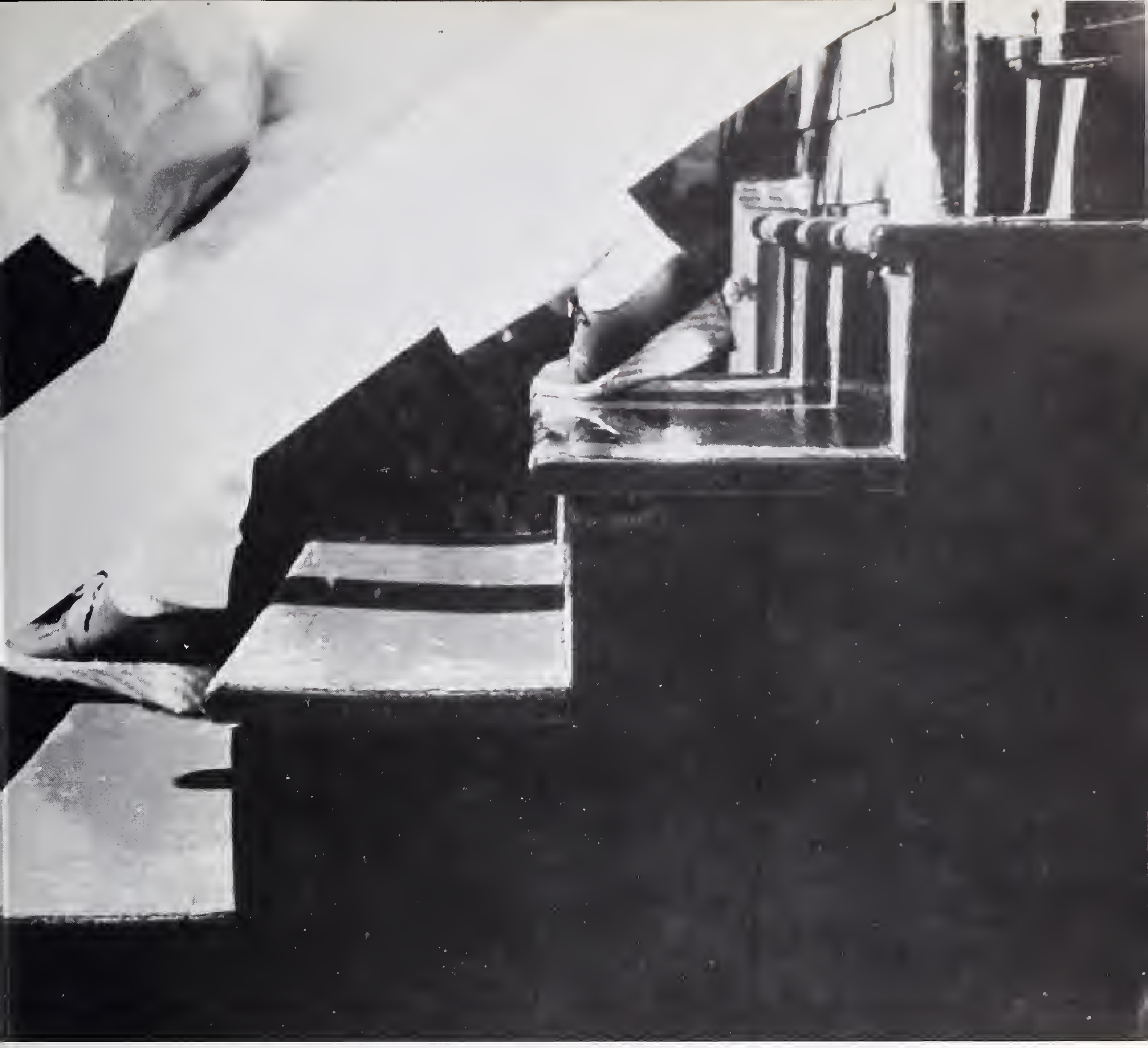
COMMENTARY - The analysis of the NBS videotapes indicated that detection of the first step was a critical component in the transition from level walking to stair movement (Templer, et al., 1978). This analysis further indicated that the detection process involves both a visual and a tactile-kinesthetic component. When the visual component is eliminated or reduced by some sort of handicap, then the tactile-kinesthetic component should be accentuated, through changes in texture on the floor, or the walls. Provision of changing auditory cues is also possible. It is important to ensure that these non-visual cues do not interfere with the non-handicapped person's use of the stairs.

Although the use of tactile cues on the floor or the wall has been recommended in some instances for the visual handicapped (Agate, 1966), there is no consensus about the most effective means of alerting users about

Figure 2.7.5

potential dangers or changes in elevation in their path. Nevertheless, the use of auditory or tactile cues appears to be a good means of alerting all users to change in their immediate path of travel.

Facing page: *The importance of understanding user behavior on stairs should not be underestimated.*



3. SUMMARY

3.1 REVIEW

In the preceding pages, a number of issues associated with stair safety were considered. Various hazardous conditions on stairways were enumerated, evidence indicating their severity and frequency was explored, and design guidelines for reducing or eliminating such hazards were presented. In general, the recommendations discussed in this report arise from the premise that many stairway accidents are caused by human perceptual and kinesthetic errors. These errors are frequently triggered by some correctable flaw in the design or construction of a stairway.

Section 1 dealt with a review of the research into the nature and causes of stair accidents. This review included a summary of the epidemiological literature relating stair accidents to different design conditions; a discussion of the NEISS in-depth survey reports of specific stair accidents; and a presentation of various code requirements. In addition, Section 1 documented research performed by the National Bureau of Standards in which numerous videotapes of successful and unsuccessful stair uses were analyzed. This overview of NBS research also examined a critical incident analysis of specific stair mishaps (Templer, et al., 1978), and a survey of stair use and inventory of residential stair characteristics (Carson, et al., 1978). Finally, Section 1 described a model of stair use behavior and discussed the importance of perceptual cues in stair negotiation.

In Section 2 the research and model described in the first Section was used to guide the development of recommendations for improving stair safety. These recommendations focused upon 7 distinct categories of stairway design and construction: (1) physical attributes of stair surfaces, (2) appearance of stair surfaces, (3) handrails, (4) physical attributes of the surrounding stairway environment, (5) appearance of the surrounding stairway environment, (6) structural integrity and quality of stairs, and (7) signs and symbols.

3.2 GENERAL RECOMMENDATIONS

The research and guidelines discussed in the preceeding sections indicate 2 equally important factors that must be considered in the design and construction of safe stairs. Conventional wisdom has suggested the need for stairs which are structurally sound and uniform. In addition, however, there is a need to ensure that the user is able to perceive the physical characteristics of the stairs in an accurate, rapid manner, free from unnecessary distractions. Thus, not only should the physical elements of the stairs be considered, but also the user's perception of these elements.

To ensure the physical integrity of a stair, it should be designed with uniform riser/tread dimensions, and with uniformly clear headroom. There should not be any projections, rough surfaces, or exposed glass areas within the stairway itself. Handrails should be provided, along with adequate light that does not vary greatly over the stair area or over time. There should be adequate contrast between the stair and its surroundings. The use of winders, and open risers should be avoided. The stairs should also be structurally sound, with stable surfaces and foundations. In summary, stairs should be designed so that their physical characteristics safely accommodate the user's desire to change levels with a space.

Yet, the provision of adequate physical facilities is not sufficient by itself. The data collected on the NBS videotapes, the incident analysis by Templer, et al., and the residential survey by Carson, et al., all indicate the importance of accurate perceptual cues in successful stair

use. These cues include visual perception of the approach to, and use of the first step, and tactile-kinesthetic perception during the remainder of the flight.

Consequently, it is essential that the stair be designed so that the user can pay maximum attention to those sensory cues necessary for a correct perception of the stair and its surroundings. In this regard, adequate lighting again becomes a critical issue, because it can maximize the detectability of visual cues. Hence, good color and lighting contrast are essential elements of safe stairway design. There should not be any deceptive visual cues, inadequate lighting levels, glare, or any other sort of visual misinformation present in the stairway. Equally important, the tactile cues should be readily recognizable and accurate. The user should be able to feel tread nosings so that his foot does not roll off the stair. He should be able to use a handrail to guide himself -- which means that the rail should be free from splinters and easily grasped. Perhaps extra tactile cues should be available for the visually handicapped user.

Finally, the stair surroundings must not be distracting to the user. Orientation edges should be minimized in the design of safe stairs. The user's attention should focus on the stair, rather than on the surrounding space. Visual distractions can be as dangerous to the stair user as incomplete or inaccurate visual or tactile information.

Achieving increased safety on stairs thus demands consideration of the role of perception in stair use, as well as the maintenance of stable physical elements of the stairs. The stair design must facilitate the user's detection of and response to the stairs. Because the user's general familiarity with stairs may lead him to overlook small deviations in stair characteristics, it is even more critical to ensure that the perceptual cues presented by the stair demand the user's attention. It is not enough, in summary, to provide sound structural stairs. The user's response to the stairs must also be considered.

3.3 DIRECTIONS FOR FUTURE RESEARCH

Future efforts should be directed toward: (1) verifying the theoretical premises which underlie the design guidelines of Section 2; (2) verifying the effectiveness of the specific design solutions recommended in the guidelines; and (3) expanding the stair safety design guidelines beyond the domain of residential occupancies.

The theoretical premises which underlie the stair safety design guidelines are given in the systematic model of stairway usage (see Section 1.2.4). This model constructs complex linkages between the user's perceptions of the stairway environment, his previous stairway experiences and expectations, and his actual stair-use behaviors. Some degree of empirical support was advanced for certain aspects of the stair use model, such as the idea that the user tests the environment when first entering a stair system. However, connections between the specific perceptual failures predicted by the model, and the accidents actually

occurring in stairway environments, remain empirically weak. Accordingly, it is necessary to conduct well-controlled empirical tests of specific hypotheses derived from the stair use model.

In addition to verifying the hypotheses derived from the stair use model, a number of specific areas related to stair safety should be researched. These include such problems as the role of color, lighting, and texture contrast in aiding visual perception of the stair, as well as the role of location-specific distractions such as orientation edges and movement in contributing to stair accidents. Changes in the user's attention during stair negotiation should also be explored in depth to determine if stairway design should be altered, or the extent of enclosure changed. Other researchable areas include a determination of the interactive role of visual, tactile, and kinesthetic perceptions in stair use. These should be evaluated particularly for their relation to good tread/riser design, and handrail considerations. Finally, the effectiveness of tactile, auditory, or other sensory cues for warning handicapped users of the presence of a stairway should be determined. Recommendations for standard warning procedures should ultimately be developed.

Throughout the presentation of stair safety guidelines in this report, results from epidemiological, experimental, and survey investigations were reported. In general, data from such studies demonstrate the existence, severity, or frequency of particular stairway hazards. However, studies providing empirical support for the particular design solutions offered by the guidelines were neither found in the stair safety literature, nor conducted during this project. Future research which tests hypotheses about the effectiveness of specific design guidelines in preventing stair accidents is, therefore, required.

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APPENDIX A: RELATIONSHIP BETWEEN STAIR GUIDELINES AND MODEL OF STAIR USE

As noted in Section 1.2.4 a model of stair use was developed to guide the development of the guidelines for stair safety. In the following pages, the relationship between each guideline and specific priorities set by the model is outlined. See Table A.1. On the following pages specific guidelines to common stair safety problems have been grouped under the following seven priorities:

1.0 accommodate the user's INTENTIONS
2.0 focus the user's ATTENTION on the stair
3.0 enable the precise DETECTION of stair conditions
4.0 PROPORTION stairs to fit user's needs
5.0 assure adequate SERVICEABILITY
6.0 provide adequate TRACTION
7.0 protect the user from injury on IMPACT

Each of these priorities constitutes one aspect of the process involved in using a stair properly. Using these priorities, it should be possible to determine the need to implement any of the corrective measures listed by considering the problems encountered by the regular users of a given flight of stairs for the parts of the stair involved.

TABLE A.1 - RELATIONSHIP BETWEEN STAIR CHARACTERISTICS AND MODEL OF STAIR USE

STAIR USE	1.0	2.0	3.0	4.0	5.0	6.0	7.0
STAIR CHARACTERISTICS	INTENTION	ATTENTION	DETECTION	PROPORTION	SERVICE-ABILITY	TRACTION	IMPACT
2.1 STAIR SURFACES: PHYSICAL CHARACT'S				2.1.1 2.1.3		2.1.2 2.1.4 2.1.5 2.1.6	2.1.7
2.2 STAIR SURFACES: APPEARANCE			2.2.1 2.2.2 2.2.3 2.2.4 2.2.5				
2.3 HANDRAILS				2.3.1-2.3.4 2.3.4 2.3.6 2.3.8 2.3.9	2.3.7		2.3.5
2.4 SURROUNDING ENV'T: PHYSICAL CHARACT'S	2.4.10	2.4.1 2.4.3	2.4.7 2.4.8 2.4.9	2.4.2		2.4.3	2.4.4 2.4.5 2.4.6
2.5 SURROUNDING ENV'T: APPEARANCE		2.5.1 2.5.2 2.5.3 2.5.6	2.5.4 2.5.5 2.5.6				
2.6 STRUCTURAL INTEGRITY				2.6.1 2.6.2	2.6.3 2.6.4	2.6.5	
2.7 SIGNS AND SYMBOLS	2.7.1 2.7.2 2.7.3 2.7.4	2.7.5 2.7.6					

1.0 INTENTIONS

2.4.10 STAIRS ACCESSIBLE TO CHILDREN UNDER 4
2.7.1 LOCATING ALTERNATE MEANS OF VERTICAL MOVEMENT
2.7.2 ORIENTATION OF THE USER TO SPECIFIC STAIR DESTINATIONS
2.7.3 ENTRIES TO LOCKED FIRE STAIRS
2.7.4 ESSENTIAL FACILITIES AT EACH LEVEL FOR THE ELDERLY OR HANDICAPPED

2.0 ATTENTION

2.4.1 CLEAR PATH OF TRAVEL FOR FLIGHTS AND LANDINGS
2.4.3 PHYSICAL CONDITIONS WHICH CAUSE THE USER TO DIVERT ATTENTION FROM THE STAIR
2.5.1 COLOR AND LIGHTING CONTRAST TO ACCENTUATE TREADS AND HANDRAILS
2.5.2 ABRUPT CHANGES IN VIEW FROM A STAIR
2.5.3 IMPACT OF VIEWS THROUGH OPEN RISERS
2.5.6 ACCENTUATION OF ALL SINGLE STEPS, 2-RISER STEPS, AND ENCROACHMENTS
2.7.5 CUES ON WALLS AND CEILINGS TO MARK THE BEGINNING AND ENDING OF STAIRS
2.7.7 NON-VISUAL CUES FOR VISUALLY HANDICAPPED USERS TO ENTRANCES TO AND EXITS FROM STAIRS

3.0 DETECTION

2.2.1 VISIBILITY OF TREAD EDGES
2.2.2 VISIBILITY OF IRREGULARITIES IN RISER/TREAD DIMENSIONS
2.2.3 TAUTNESS OF CARPET AND RUNNER MATERIALS AGAINST THE NOSING
2.2.4 GLARE REFLECTED FROM THE STAIR TREADS
2.2.5 HIGH-CONTRAST SHADOWS PARALLEL TO TREAD EDGES
2.4.7 STAIR FLIGHTS WHICH ARE NOT READILY VISIBILE
2.4.8 ILLUMINATION OF STAIRS
2.4.9 CONTROL SWITCHES ON THE TOP AND BOTTOM LANDINGS
2.5.4 HOTSPOTS OF DIRECT, REFLECTED, OR DIFFUSED LIGHT WITHIN THE STAIR USER'S NORMAL FIELD OF VISION
2.5.5 CHANGES IN LIGHT LEVEL BETWEEN STAIRS AND THEIR SURROUNDINGS

4.0 PROPORTION

2.1.1 RISER/TREAD DIMENSIONS
2.1.2 TIGHT AND UNIFORM TREAD COVERINGS
2.3.1 CONTINUOUS HANDRAILS
2.3.2 HANDRAILS COMFORTABLE TO GRASP
2.3.3 HANDRAIL- GUARDRAIL ON OPEN-SIDED STAIRS
2.3.4 DUAL CENTER HANDRAIL FOR WIDE, HEAVILY USED STAIRS
2.3.6 HANDRAILS ON STAIRS FREQUENTLY USED BY THE ELDERLY OR HANDICAPPED
2.3.8 INTERMEDIATE HANDRAIL FOR CHILDREN UP TO 6 YEARS OLD
2.3.9 OPENINGS IN HANDRAIL SUPPORTS (FOR CHILDREN)
2.4.2 CLEAR HEADROOM THROUGHOUT THE FLIGHT

2.6.1 EXCESSIVELY STEEP STAIRS THAT ARE FREQUENTLY USED
2.6.2 EXCESSIVELY IRREGULAR STAIRS

5.0 STRUCTURAL SERVICEABILITY

2.3.7 SUPPORT AT THE ENDS OF HANDRAILS
2.6.3 BROKEN TREADS, HANDRAILS, NOSINGS, AND SPINDLES; LOOSE NAILS, BOLTS, BRACKETS, OR OTHER FASTENERS
2.6.4 DILAPIDATED WOOD, METAL-FRAMED, OR CONCRETE STAIRWAYS

6.0 TRACTION

2.1.2 INTERNALLY STABLE WALKING SURFACE
2.1.4 UNIFORM SLIP-RESISTANCE ON EACH TREAD THROUGHOUT THE RUN OF THE STAIR
2.1.5 SLIP-RESISTANCE ON STAIRS EXPOSED TO PRECIPITATION, AND ON SURFACES THAT DISSIPATE MOISTURE ON OUTDOOR STAIRS
2.1.6 SLIP-RESISTANCE ON LONG OR SLOPING TREADS AND SLOPING LANDINGS
2.4.3 PHYSICAL CONDITIONS WHICH CAUSE THE USER TO DIVERT ATTENTION FROM THE STAIR
2.6.5 STAIRS WHICH HAVE TREADS SEVERELY CANTED TO THE RIGHT OR LEFT

7.0 IMPACT

2.1.7 SLIGHTLY ROUNDED NOSINGS
2.3.5 HAND- OR GUARD-RAIL TERMINATIONS
2.4.4 HOOKS, BRACKETS, AND OTHER PROJECTIONS IN THE USER'S CLEAR PATH OF TRAVEL
2.4.5 SPLINTERS, PROTRUSIONS, SHARP EDGES, AND ABRASIVES ON CONTACT SURFACES
2.4.6 GLASS AREAS IN OR NEAR FLIGHTS OF STAIRS AND LOWER LANDINGS

APPENDIX B: RETROFIT PRINCIPLES

The information described in the guidelines for stair safety may be used for either new construction or for retrofit of existing stairways. When stairs are repaired, it is important to consider the following general principles so that the stairs are, in fact, made more safe.

(1) Upgrade the stairs most frequently used by the most vulnerable people first. Children under the age of 5 have twice as many stair accidents as their proportion of the population suggests they should. Accidents among older people, while less frequent, are much more likely to lead to serious injuries or even death. People with hearing problems, epilepsy, frequent dizzy spells, or similar medical problems are vulnerable to having these conditions aggravated by the effort required to use the stair. Person who wear bifocals or hearing aides are particularly susceptible to subtle deceptions on stairs.

(2) Avoid piecemeal repairs and temporary patches on stairs. A flight of stairs is a single unit and any improvements that are made should contribute to the uniformity of the materials and dimensions of the whole assembly from landing to landing. One-shot improvements like tacking down a rubber mat on one tread where the carpet appears worn, cement infill for a broken concrete nosing, or a piece of framing lumber to replace a single hardwood tread are often worse than no improvements at all. A lot of accidents are caused by makeshift repairs that the householder thought would make the stairs more safe.

(3) Do not try to learn new skills while fixing the stairs. Some improvements or repairs on stairs require expertise that most householders do not have. When it comes to stretching a carpet or replacing resilient tile it may be more economical from a safety standpoint to have the work done professionally. Proper installation of most materials is far more critical on a stair than it is elsewhere in the home.

(4) There are upper, as well as lower limits to safe conditions on stairs. There is a relatively wide range of material and dimensional characteristics that can support safe behavior on stairs, yet treads can be too long and risers can be too low for safe passage. Treads that are so resistant to slipping that the foot will not move when it should or lights that are so intense that all visual information is washed out can be just as hazardous as icy stairs in the dark. Safe practices, if carried to extremes, can produce unsafe stairs.

(5) Compensate for all defects that cannot be corrected. While the dimensional characteristics of a stair are seldom amenable to change, it is often possible to alert the user to steep or irregular stairs, low headroom or a missing landing with a strip of reflective tape, special lighting, or a warning sign. It may also

be possible to add extra handrails or more slip-resistant tread materials where precarious situations cannot be avoided. The key to stair safety does not lie so much in the hazard itself as it does in the user's awareness of his vulnerability to the hazard. If someone sees a short tread or a high riser he can grab the handrail, step cautiously, and usually avoid an accident. On the other hand, if there is no handrail or the stairs are difficult to see, he may be less fortunate.

(6) Avoid repairs or rennovations near the stairs that could create new hazards. A new exhaust fan over an exit stair could lead the user to turn his head and miss an otherwise visible hazard. A new window near the stairs can introduce shadows or patches of glare that confound the user's ability to see the edge of a tread at certain times of the day. Repaving a driveway can shorten the bottom riser on an adjacent stair by the depth of the paving and thereby introduce a non-uniform bottom step. Safe stairs are as dependent on the conditions which surround them as they are on the materials and dimensions of the stair itself. Changes in the surroundings can often negate otherwise safe conditions on a stair.

APPENDIX C: GLOSSARY

Accident -

1. "An unpremediated event resulting in a recognizable injury" (WHO: 1957).
2. "An event, independent of the will of man, caused by a quickly acting extraneous force, and manifesting itself by an injury to body or mind."
3. "An unplanned or unexpected event in a sequence of events."
4. "In a chain of events, each of which is planned or controlled, there occurs an unplanned event which, being the result of some non-adjustive act on the part of the individual (variously caused), may or may not result in an injury. This is an accident."
5. "An accident is the event that occurs at that point in time in the accident sequence when the preceding factors or potentials interact to produce irreversible and recognizable results."
6. "Disabled for 24 hours or more."
7. "Unexpected physical and chemical injuries to the body and other structures." (Haddon: 1967)
8. "Any actual or presumed trauma following an incident for which direct medical or dental attention is obtained." (Dickson: 1964).
9. "An event that takes place without one's foresight or expectation; an undesigned and unforseen occurrence of an inflictive or unfortunate character; a mishap resulting in an injury to a person or damage to a thing." (Webster's Dictionary)

Baluster - "A post in a balustrade of a flight of stairs which supports a handrail". (Templer: 1974)

Coefficient of Friction - The coefficient of friction between 2 surfaces is the ratio of the force required to move 1 surface over the other to the total force pressing the 2 surfaces together. (Ekkebus and Killey: 1971)

Energy Expenditure - Amount of energy used measured in cal/kg-in. Measured by monitoring the consumption of oxygen during the performance of a task. (Templer: 1974)

Epidemiological Research - the application of sampling techniques to a large body of information to determine the extent and severity of a given problem within a diverse population.

Finishes - The finished material on a staircase; e.g. paint, linoleum, carpet, etc.

Flight - A series of steps without an intervening platform. (Teledyne-Brown: 1972)

Force - Amount of pressure applied by foot when ascending and descending a stairway. (Harper: 1962)

Amount of pressure applied by foot when walking. (Harper, Warlow and Clarke: 1967)

Force Plate - An instrument used to measure the amount of pressure applied by the foot when ascending and descending the stairway. (Harper: 1962)
An instrument used to measure the amount of pressure applied by the foot when walking. (Harper, Warlow & Clarke: 1967a) (Harper, Warlow & Clarke: 1967)

Frequency - Number of accidents per individual, as expressed by the empirical data, or as expected by 1) chance
2) single-biased hypothesis
3) unequal liability hypothesis.

Gait, Human - The manner of walking or stepping; carriage of the body in going, walking. (Universal Dictionary)

Handrail - An inclined structural member paralleling the slope of the stair, intended for grasping by the hand during ascent and descent of the stair. (Teledyne-Brown: 1972)

Headroom - The vertical distance from the underside of another flight of stairs or a ceiling above a stair to an inclined line that is tangent to the nosings of the steps of the stair. (Teledyne-Brown: 1972)

Kinesthetic - "The sensation of position, movement, tension, etc. of parts of the body, perceived through nerve and organs in muscles, tendons, and joints." Webster's New World Dictionary 2nd Edition.

Landing - The floor at the top (or bottom) of a stair, or a platform between flights of a stair. (Teledyne-Brown: 1972)

Newel, Newel Post - A main post supporting the handrail of a stair at the top, bottom or on a landing. (Teledyne-Brown: 1972)

Non-Uniformity - variation or lack of uniformity of dimensions of treads or risers through a flight of stairs.

Nose, Nosing - The projection of the front edge of the treads beyond the front face of the riser below. (Teledyne-Brown: 1972)

Open Riser - A step without a riser member. (Teledyne-Brown: 1972)

Orientation Edge - An abrupt change from enclosed surroundings (of a stairway) to an open, unrestricted view of a larger space.

Overhang - The projection of the tread beyond the back edge of the tread below. (Teledyne-Brown: 1972)

Perception - The intersect of sensation and cognition. This complex act refers to the process of selecting, analyzing and synthesizing sensory stimuli so that interpretation may follow. (Lerea and Rathey: 1972)

Posture - "Ambulation on any incline demands a postural change. The body cannot maintain an angle perpendicular to the slope, but must be adjusted forward for ascent and backward for descent in order to maintain the center of gravity over the base, the feet; and the extent of the adjustment is related to the pitch of the incline." (Templer: 1974)

Railing - A barrier at 1 or both sides of the stair constructed so as to prevent individuals from falling off the side of the stair. (Jones & Williams: 1967)

Railing, Closed - A railing which is formed by a short wall extending above the stair. (Jones & Williams: 1967)

Railing - A barrier at 1 or both sides of the stair, constructed so as to prevent individuals from falling off the side of the stair. (Teledyne-Brown: 1972)

Ramp - Inclined plane for passage of traffic. (Templer: 1974)

Rise - the vertical distance from the top of 1 tread to the top of the next tread. (Teledyne-Brown: 1972)

Riser - The vertical face of a step, or the member forming this surface. (Teledyne-Brown: 1972)

Run - The horizontal distance from vertical riser to vertical riser, or from nose tip to nose tip.

Slope - The inclined plane of the stairs established by the relationship of the rise to run of the steps of the stairway. (Teledyne-Brown: 1972)

Stair - A series of steps, or flights of steps connected by landings, for passing from one level to another. (Teledyne-Brown: 1972)

Staircase - Stair; also sometimes used to designate the entire assemblage, including railing, balusters, etc. (Teledyne-Brown: 1972)

Stairway - Often used synonymously with stairwell and/or stair. (Teledyne-Brown: 1972)

Stairwell - The space in the building occupied by the stair. (Teledyne-Brown: 1972)

Step - A single unit of level change in a stair consisting of 1 riser and 1 tread. (Teledyne-Brown: 1972)

Step Length - The distance between successive contact points of the opposite feet. (M. P. Murray: 1966)

Step Distance - It is determined by measuring the distance between the toe point of 1 ft. and the heel point of the opposite foot. (Ogg: 1963)

Steep - A stairway with a slope of 40° (with riser height 8.25 in. and tread width 9.70 in.).

APPENDIX D: CODE REVIEW DETAILS

In 1974, the major codes required a minimum stairway width of either 44 in. or 36 in. depending upon the occupancy. The minimum stairway headroom dimension ranged from 6 ft. 4 in. for basement stairs for the HUD minimum property standards (MPS) to 7 ft. 0 in. In general, landing width was required to be not less than the least dimension of the stairway with minimum length varying from 2 ft. 6 in. to 4 ft. 0 in. The recommended maximum height of risers varied greatly from 7-1/4 in. to 8-1/4 in., while minimum tread depth varied from 9 in. to 11 in. There was also disagreement about the minimum number of risers (often 2 or 3) and the maximum number of risers between landings (given as 18 in the MPS). The Life-Safety Code (LSC), the Uniform Building Code (UBS), the Standard Building Code (SBC), and the Building Officials Code of America (BOCA), all required means of egress to be illuminated with not less than 1 footcandle (fc) at the floor level, while the MPS required 5 footcandles (fc) for care-type housing and permanent electric light fixtures in 1-2 family residences.

The codes, in general, required handrails where needed to keep occupants from falling, as from open landings and stairs. Specifications for handrail height varied between 30 in. and 42 in. among the codes, with only the LSC requiring guards and handrails to continue for the full length of each flight of stairs. Intermediate handrails were required for all stairways wider than 66 in. or 88 in., depending upon the particular code.

There was also considerable variation among the codes with respect to the requirement for tread/riser uniformity. Several, such as BOCA, did not specify any particular uniformity while others such as LSC and UBC, specified only a 3/16 in. maximum variation in risers and treads in any flight of stairs. Others specified only that there be uniformity in riser/tread dimensions throughout the flight of stairs.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report summarizes information and research in the area of stair use and provides design guidelines for improving stair safety. These guidelines are directed toward seven major categories of stairway design and construction: (1) structural integrity and quality of stairs, (2) physical attributes of stair surfaces, (3) appearance of stair surfaces, (4) handrails , (5) physical attributes of the surrounding stairway environment, (6) appearance of the surrounding stairway environment, and (7) signs and symbols.

In general, the recommendations offered in this report derive from the premise that stairway accidents are caused by human perceptual errors, which are frequently triggered by some flaw in the design or construction of stairways themselves. Evidence describing the severity and frequency of residential stairway hazards, and supporting premises underlying design guidelines were obtained from epidemiological, experimental, exploratory, and survey research sources. General directions for future investigation are suggested.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Accidents; architectural design; architectural psychology; architectural research; building codes; building design; building regulatory standards; floor coverings; home safety; safety standards; stair safety; stairway design.

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